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VEHICLE EMISSIONS SURVEILLANCE STUDY

AUGUST 20, 1971

IN SUPPORT OF:
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FOR
COORDINATING RESEARCH COUNCIL, INC.
THIRTY ROCKEFELLER PLAZA
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AND

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PREFACE

The work presented herein is the product of a joint effort by TRW Systems Group and its subcontractor, Scott Research Laboratories. TRW, as the prime contractor, was responsible for overall program management, experimental design, data management and analysis, and the economic-effectiveness study. Scott conducted the emission instrument evaluation and acquired and tested all of the study vehicles. Scott also provided technical assistance in selecting emission test procedures and in evaluating the test results.

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EXECUTIVE SUMMARY

The objective of the study reported herein is to recommend optimal procedures for conducting an automobile exhaust emissions field surveillance program. The primary objective of this field surveillance program is to characterize vehicular emissions to the atmosphere for specific regions within the United States. Alternatively, the data may be used to evaluate regional differences in vehicular emissions such as might occur because of different vehicle maintenance policies. This study was performed by TRW Systems Group under contract APRAC Project CAPE-13-68 which was jointly sponsored by the Coordinating Research Council (CRC) and the Environmental Protection Agency (EPA).

Procedures to be established for conducting a vehicle exhaust emissions surveillance program included:

- Methods of controlling emission measurement standards (inter- and intra-laboratory control)
- Procedures for identifying and acquiring vehicle samples from a general population
- Procedures for establishing selected temperature states of the vehicle power train prior to emissions testing
- Number of 7-mode Federal test cycle replications over which emissions are to be measured.

The equipment, facilities and manpower required to support these procedures were also to be defined and the cost of alternate programs evaluated.

Test procedures were to be determined within the following framework:

- The minimum complexity of a surveillance test cycle was to be limited to one cycle of the current 7-mode, 7-cycle Federal procedure (Reference 45 CFR Part 85). The test procedures developed, therefore, specify the number of replications of the basic cycle as opposed to developing a new test cycle.
- Although primary emphasis was to be placed on using composite concentration emissions, which are calculated from measurements at selected locations within the driving cycle, the general impact of making a direct mass emissions measurement was also to be assessed.

The approach taken to meet these objectives was to develop quantitative error models relating HC, CO, and NO_x emissions measurement variability to the independent parameters which define test procedures as well as to the performance of basic test equipment. The capital and operating costs were then evaluated for the same set of procedures and equipment. A figure-of-merit system was established and used to evaluate the relative merit of a selected set of surveillance program options. The figure-of-merit system selected (pay-off function) was the product of the total variability in predicting emissions (estimated population standard error about the mean emissions level) and the total system cost. Variables to be optimized included the general quality of the instrumentation, number of test cycle replications and vehicle sample size. The confidence level at which the population standard error was to be estimated was assumed to be an input to the system design.

Historical data were first reviewed for use in the study. These data included the EPA and California Air Resources Board vehicle emissions surveillance data as well as Scott Research Laboratory's gas blend cross-reference service data. These data were used to establish error models relating emissions measurement variability, respectively, to sample composition within a vehicle model year, to sample composition between vehicle model years, and to instrument calibration procedure between laboratories. In addition, data were developed under the contract to establish emission variability when alternate test procedures were used. Specifically, emissions sensitivity to power train temperature state was established for 11 basic engine classes.

The synthesized data were used to construct a mathematical system model which was then used to evaluate the impact of various procedures and equipment configurations on the system figure of merit.

The results of this study fall into two general categories:

- General surveillance program guidelines which were developed out of our study experience but which were not amenable to mathematical modeling because of complexity and/or lack of definitive data.
- Specific procedures and equipment configurations which were optimized using the surveillance system model.

Results within each category are summarized in the following sections.

GENERAL PROGRAM GUIDELINES

The general guidelines established for conducting a field surveillance program relate to methods for maintaining instrument standards to minimize precision (repeatability) and accuracy (bias) errors within and between laboratories and procedures for identifying and acquiring a vehicle sample from a general population. The former procedures are important in characterizing the emissions of individual vehicles while the latter procedure is important when predicting overall population emissions levels.

The following procedures are recommended for ensuring precise and accurate emissions measurements. These procedures are intended to supplement and not replace those of the 7-mode Federal procedure, Reference 45 CFR Part 85.

- When more than one laboratory is involved in performing a surveillance program, vehicles of the same general class should be divided equally between laboratories to avoid the possibility of introducing regional or laboratory procedures biases when evaluating the performance of the particular class relative to other classes.
- Periodic cross-reference checks of instrument systems using known gases should be performed. Four to six different gas blends should be used, particularly for CO and CO₂ which have highly nonlinear calibration curves.
- Calibration points (approximately six) should be fitted with a logarithmic curve (Beer's Law model). It is suggested provisionally that the standard error of the curve fit should not exceed 1.0% of the full scale measurement nor should an individual calibration point differ by more than 3% from the value predicted by the curve fit.
- The general maintenance state of the instrument system should be monitored using quality control type charts to record the variation of both the gain setting and mid-span point. Control limits should be selected for these quantities which are compatible with the accuracy of the span gases used and with the inherent instrument component performance.

The following are important considerations in selecting a vehicle sample from a regional population either when a completely random sample cannot be obtained or when a small sample (less than 250 vehicles) is to be used.

- The sample should be matched with the general population, at least with respect to the distribution of engine displacements and vehicle total mileage. Because idle CO exhaust concentration and engine misfire characterize the state of two major engine systems, it also is important that the frequency and extent of the maladjustment or malfunction of these quantities in the test sample be representative of the general population.
- When the surveillance program includes testing vehicles of more than one model year, data can be pooled between model years providing that the emissions control equipment are of a single generic type and that the exhaust emissions are shown to be statistically similar.
- When sampled vehicle populations are shown with an acceptable level of statistical significance to have attributes which are different from the general population, then either the sample itself must be suitably adjusted or empirical corrections applied to the emissions data.

OPTIMAL PROCEDURES AND SYSTEM CONFIGURATIONS

Optimal procedures and system configurations to be applied in vehicle emissions surveillance programs were defined for three basic temperature conditioning test procedures:

- A 12-hour cold soak to cool the power train to ambient temperatures as specified in the current Federal test procedure
- Accelerated power train cooling to near ambient temperature conditioning
- Temperature conditioning to a stabilized engine operating temperature.

For the latter two cases empirical correction factors were developed relating the emissions measured at prescribed temperature states to those which would have been measured had the full Federal test procedure been used. These correction factors essentially correct the bias error. These bias error correction factors, of course, also introduce uncertainty. The resulting variability of the empirically developed temperature bias correction factor must be combined with other procedure errors to estimate a total error for these test procedures.

Additional component errors were also estimated including those inherent in the measurement system, the within vehicle variability, and the between vehicle variability. The emissions variability was found to become progressively larger for error components in the order just listed. For

example, HC standard errors about the respective means were found to be 7 ppm for the instrumentation, 27 ppm for within vehicle variability, and 97 ppm for between vehicle variability.

The following general conclusions were reached:

- The CO emissions variability as reflected by the estimate of its population standard error is larger than NO_x and HC emissions and therefore, will generally control the size of the test fleet.
- Relative to their mean emissions, both 7-mode mass and concentration measurements are nearly identical within and between vehicle variability.
- Mass emissions (particularly CO) have significantly greater sensitivities to engine temperature state than do composite emissions.
- Regional biases may exist in emission measurement programs which are primarily attributable to vehicle differences (i.e., maintenance state).

The following specific conclusions were reached with regard to test procedures and system configurations:

- The test variable having the greatest impact on the total emissions standard error was found to be the number of cycle replications used during the emission test for vehicle sample sizes between 100 and 1000. The most cost-effective number of cycle replications was found to be between five and six and was not found to be influenced strongly by other procedural variables.
- The most cost-effective test procedure for a surveillance program involving more than 100 vehicles is to condition the power train to a stable operating temperature and to perform a hot cycle emission test using five cycle replications.
- An accelerated cool-down procedure which involves circulating cooling water through the block while blowing air over the radiator is cost-effective for surveillance programs of more than 240-500 test vehicles, depending on whether HC and/or CO emissions are to be investigated.
- Both cost and the selected figure of merit show the shortened test procedures to be attractive. The fixed cost of establishing the factor to correct emissions measured with short procedures to those which would have been measured by the Federal procedure tends to reduce the effectiveness of these procedures for programs using small sample sizes.

- Increasing required confidence levels in estimating population emissions variability significantly increases the cost of a surveillance program. For example, an increase in confidence level from 95 to 99% requires nearly twice as many vehicle tests.

1.0 INTRODUCTION

A national program to control exhaust emissions from automobiles generates a requirement for surveillance activities having several objectives.

- Predicting the total emissions to the atmosphere in various cities and/or air pollution control regions as a step toward establishing air quality goals and attendant emission standards.
- Comparing various control alternatives such as programs of mandatory vehicle inspection and maintenance by directly contrasting emissions between regions in which alternate procedures have been implemented.
- Examining the effectiveness of control equipment installed on automobiles both for its performance when new and also to establish the nature and extent of its performance degradation when used by the general public.

The former two surveillance activities are those addressed in this study.

Currently implemented vehicular emissions surveillance programs are of two general types:

- EPA Regional Surveillance Programs which use the specified Federal emission test procedure (Reference CFR-45, Part 85) with vehicles acquired largely from rental or private sources.
- The California Air Resources Board program which uses a shortened version of the Federal test procedure with vehicles acquired from the public at mobile test sites.

In the former program, emissions data were acquired either in EPA facilities using a fleet of rental vehicles or by contractors specializing in vehicle emissions testing. Because of the complex nature of the Federal emissions test procedure and the requirement to acquire vehicles, these programs tend to be expensive and to inconvenience participants who make their vehicle available for test. The emissions test results, providing that the sample is correctly selected, are definitive and need only minor corrections to provide either an estimate of emissions to the atmosphere or a determination of vehicle compliance to the Federal standards.

The California program minimizes emissions test costs because direct vehicle acquisition costs are not incurred and because vehicles are tested as received with a short version of the Federal emission test procedure. Further economies are effected by testing at mobile sites. Investment

costs associated with the requirements for an environmentally controlled building for vehicle 12-hour cold soak storage are not required.

Because of the magnitude of the surveillance task, it is important that it be performed with maximum effectiveness. It was the purpose of this study to investigate alternate procedures for performing surveillance and to define an optimum surveillance program. Obviously, different "optimum" procedures will result as the imposed requirements on the surveillance program are changed. Goals with respect to the precision and accuracy of emissions measurements have a profound effect upon program cost. Because these goals have not been clearly defined, the approach used in this program was to establish the nature and magnitude of each component of emissions measurement variability for a selected range of test procedure and equipment options. The total emission variability then was estimated as a function of such major test variables as the required level of confidence and the test sample size.

A comprehensive model was assembled for estimating total surveillance program costs for all of the test procedure and equipment options.

Surveillance program procedural and equipment options were compared for predicted emissions measurement variability and cost directly as well as using a figure of merit based upon the product of test variability and cost.

A number of ground rules were established by the CRC APRAC CAPE-13 Steering Committee to limit the possible extent of this program. These bounding assumptions were:

- Surveillance test cycles (driving profiles) were to be limited to varying numbers of replications of the basic 7-mode test cycle. New driving cycles were not to be developed for surveillance purposes.
- Procedures were to be developed for rapidly cooling vehicle power trains to temperature states near ambient before emissions testing as well as for establishing a stabilized hot operating temperature condition.
- The spectrum of test procedures considered was to include the use of the current Federal procedure.

Section 2.0 describes the range of surveillance procedures, equipment and test site options which were modeled in this program and presents some historical data to support the options selected.

Section 3.0 presents historical as well as program developed data to support the modeling of the variability attributable to various error sources as well as costs.

Section 4.0 summarizes the actual mathematical relationships which describe component errors and costs that were programmed on the computer and were the basis for the subsequent definition of optimum procedures.

Section 5.0 presents the results of the analyses including the definition of optimum procedures.

2.0 SURVEILLANCE SYSTEM DEFINITION

The possible surveillance system configurations described in this section form the basis for the mathematical modeling and computer simulation activities described in Sections 3.0 and 4.0. The system configurations discussed below are not intended to satisfy all possible surveillance program applications. Rather, emphasis has been placed on concepts, policies, and procedures thought to be supportive of the stated objective of predicting emissions to the atmosphere using test procedures closely related to the Federal procedures described in Reference 45 CFR, Part 85, of the Federal Registrar. A brief discussion of the impact of the different procedures required for testing vehicles for compliance to Federal standards also is presented.

To assist in defining a surveillance system, visits were made to the California Air Resources Board, the Environmental Protection Agency, and the General Motors Corporation, all of whom were conducting surveillance programs within the Los Angeles Basin. These agencies were visited to determine their:

- General program objectives
- Methods of acquiring vehicles
- Procedures for conducting the emission test
- Data acquisition and reduction procedures.

The information obtained is summarized by the above major headings in Table 2-1. In addition to the indicated differences in the use of the Federal test procedure and instrumentation and calibration procedures, other procedure differences were also present in these programs reflecting their objectives and budgetary constraints. Information obtained about these surveillance programs is used in this section to develop general guidelines and procedures for conducting a vehicle surveillance program.

TABLE 2-1

SURVEILLANCE PROGRAMS IN THE LOS ANGELES BASIN

<u>Agency</u>	<u>Objective</u>	<u>Test Procedure</u>	<u>Laboratory Control</u>	<u>Vehicle Acquisition</u>
General Motors Corp. Emissions Laboratory	Support customer service & evaluate in-use control performance.	Full Federal test, vehicle stored in- side for cold soak. Electronic analyzer diagnosis.	Pre & post span check, calibra- tion once/mo. Applied Dynamics data processor. Uses Scott cross reference gas.	Random selection from L.A. basin to reflect regional population.
California Air Resources Board	Monitor certification effectiveness & provide data for establishing air quality.	One cycle warm-up, two cycles for data collection. Vehicle tested as received.	Pre & post span check, calibra- tion every 2 mo. Raw data goes to CARB for proces- sing. Uses Scott cross reference gas.	Random selection from Dept. of Motor Vehicles parking lot. No attempt to match popula- tion at test site.
Environmental Protection Agency	Monitor certification effectiveness & provide data for establishing air quality.	Full Federal test, vehicle stored in- side for cold soak.	Pre & post span check, calibra- tion once/mo. Averaged mode data goes to Ypsilanti for processing. Use Scott cross ref- erence gas.	Rental or private vehicles scheduled in every 4000 miles

2.1 Facility Configurations and Equipment Requirements

Both fixed site and mobile surveillance stations are considered facilities for performing emissions testing. Mobile units may be brought to areas of high vehicle density such as the parking lots of the Department of Motor Vehicles and large industrial organizations. They also may be used beside well-traveled surface streets. A typical mobile unit shown in Figure 2-1 would have a conventional emissions instrument cart as well as a portable power generator. Fixed sites may include facilities specifically constructed for surveillance, inspection stations additionally equipped to perform this function, or private testing organizations specializing in emissions testing. When the functions of surveillance and inspection are shared, both tests may be conducted serially on randomly selected vehicles providing that hot-start testing for surveillance is acceptable. Alternatively, a special surveillance shift can be run after hours in order to provide time for cold-start temperature conditioning. When the full Federal test procedure is to be used, an environmentally controlled area is required of sufficient size to store vehicles for the entire day's testing. Alternatively, if accelerated temperature conditioning is used, parking area and ancillary equipment must be allocated for this purpose.

In addition to the basic facility, three types of emission measurement related equipment are required:

- A chassis dynamometer
- An emission measurement system
- A data acquisition, recording and reduction system.

The dynamometer must be capable of loading the vehicle power train under both cruise and transient driving conditions. A driving cycle(s) (velocity-time trace) is prescribed which must be accurately followed. For this purpose, the vehicle operator is provided with a driver aid which continuously displays and compares the prescribed driving cycle with the one actually being driven.

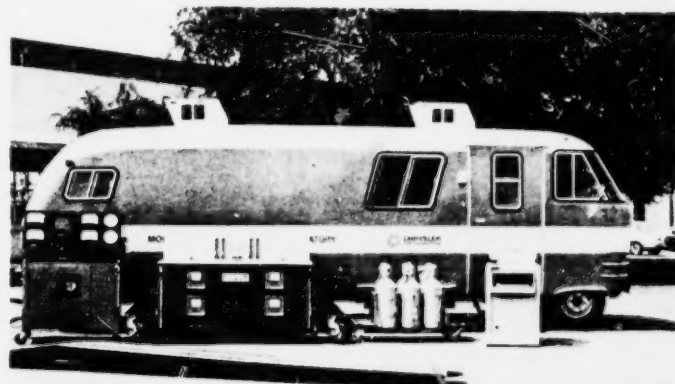
FIGURE 2-1
MOBILE EXHAUST CONTROL LABORATORY

The laboratory pictured is constructed on a 1-ton chassis. The basic mobile laboratory involves:

- V-8 engine with Automatic Transmission
- Two "in-the-roof" air-conditioners
- A 16,000 Btu forced-air and ducted gas heater
- Reinforced sidewalls for added strength
- Large entry door for loading and removing instrumentation and gear
- Special lightweight fold-away loading ramp
- Two 5,000 watt frequency-controlled 110V generators
- Ample work bench and desk area covered with chemical-resistant Formica.

Instrumentation in the laboratory includes:

- Shock mounted, highly moveable nondispersive infrared analysis system as recommended by the Auto Manufacturers Association and the Federal Government (for the measurement of CO, CO₂, and HC)
- Beckman Model 82 Computer used in conjunction with the auto exhaust analysis system
- Engine analyzer
- Trailer mounted Clayton Dynamometer with two interchangeable flywheels (3000 & 4000 pounds), designed for portability and quick set-up.



Four emissions measurements are required by the current Federal test procedure; CO, CO₂, and two ranges of HC. The prescribed accuracy and response of the Federal procedure has limited instruments to the non-dispersive infrared type. These are laboratory type instruments which require careful calibration, audit, and preventive maintenance to assure quality measurements. Calibration and purge gases are required to adjust instrument gain and to clean the instrumentation sample train, respectively.

Several electronic data acquisition/reduction systems are commercially available which convert the analog signal to concentration units, select and read the applicable portions of the emissions trace, perform the weighting and summing operations, and output the results digitally.

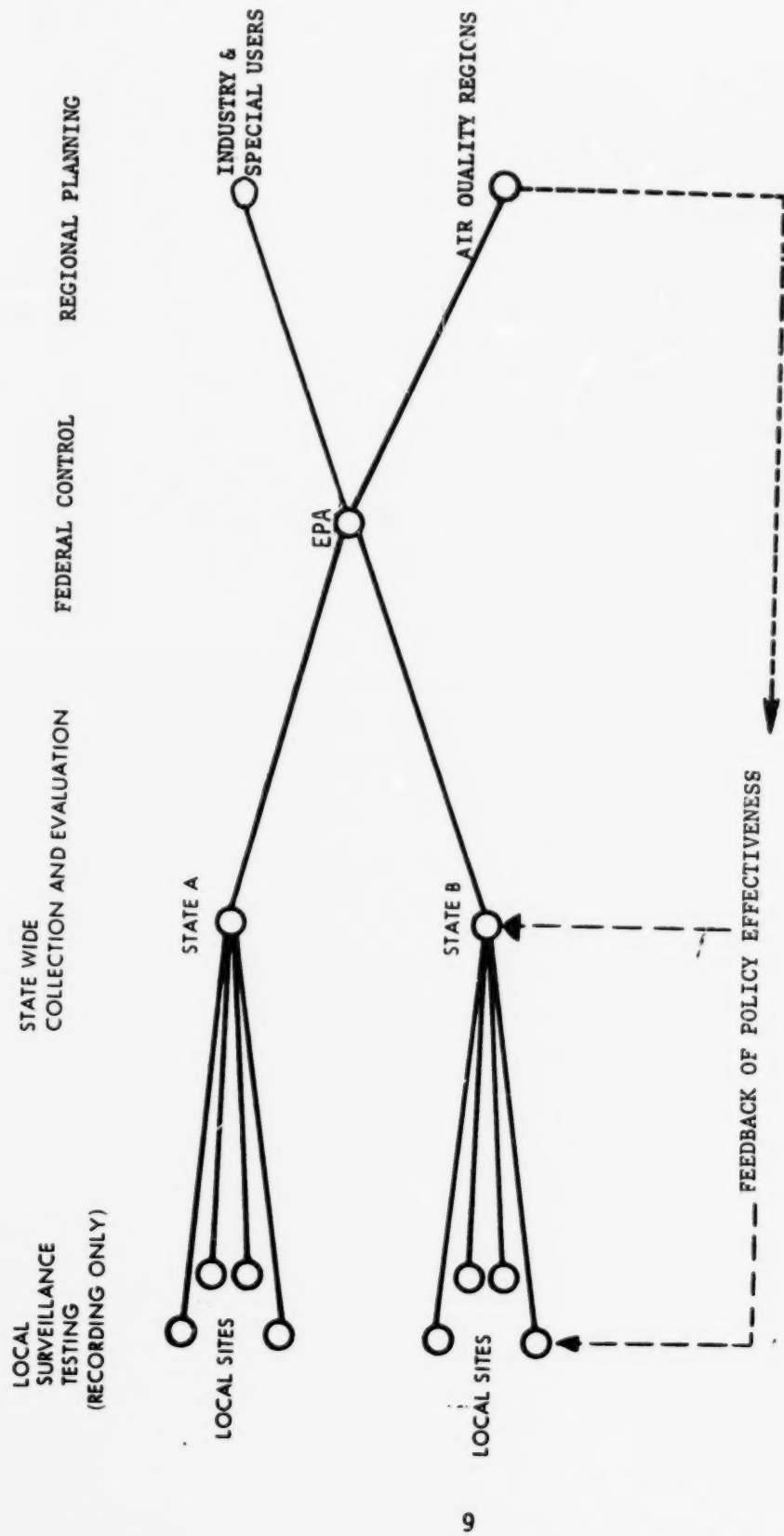
Implementation of a large scale surveillance program requires the involvement of governmental agencies at several administrative levels. Figure 2-2 illustrates possible administrative actions and information flow relationships between various levels. This figure suggests the following assignment of responsibilities:

- Local - monitoring and recording
- State - collection and evaluation
- Regional - appraising and policy definition
- Federal - control

2.2 Considerations in Selecting Operational Procedures

A number of procedures can be used with the equipment and facilities discussed in Section 2.1 to obtain vehicle emissions measurements. Operational procedures to be defined and characterized with respect to their cost and error impact on a vehicle emissions surveillance program are:

- Test procedures for obtaining emissions measurements
- Procedures for selecting and acquiring vehicles.



SURVEILLANCE INFORMATION SYSTEM
FIGURE 2-2

2.2.1 Emissions Measurement Procedures

Emissions test procedures to be established involve:

- The type or amount of vehicle power train temperature conditioning
- The number of times the 7-mode driving cycle is to be replicated
- Criteria and controls for laboratory procedures.

These procedures have a strong influence on the measurement error which has three components:

- Inherent vehicle variability caused by deposits, unstable adjustments, etc.
- Test procedure accuracy and repeatability
- Inherent variability in the instrumentation system.

The first class of error is discussed elsewhere; the latter error sources are discussed below. These errors for different test procedures will be used in error-versus-cost relationships to support the selection of emission test procedures.

Effect of Power Train Temperature State on Measurement Accuracy

To determine the relative significance of the various errors resulting from the driving cycle used for emission measurements, several analyses were performed. The first of these was a statistical evaluation of the relationship between the composite Federal emissions level and the weighted and corrected emissions determined individually for the six cycles recorded during the Federal test. The results for hydrocarbon and carbon monoxide emissions are shown in Figures 2-3 and 2-4 using data from Reference 1.

As indicated by the "t" statistics, the first test cycle produces emissions which correlate better than those of any other cycle with the full procedure composite emissions. The seventh cycle ranks second. This indicates the importance of nearly complete cold temperature conditioning of the vehicle before making emissions measurements if results similar to those given by the Federal procedure are to be obtained.

The cycle-to-cycle variation of emissions measured during cold-start Federal testing is also indicated on Figures 2-3 and 2-4. It is seen that the CO emission level stabilizes at about the third cycle while the HC emission level has not quite stabilized even by the seventh cycle (although for practical purposes it may be considered stabilized). The sample standard deviation of the emission levels for both CO and HC tends to stabilize by the end of the third cycle. This fact will be used later to develop an error model (Section 4.0) which is sensitive to cycle repeatability only and which is free of bias caused by temperature effects.

Two viable procedures are considered in this report for correcting the emission bias error caused by power train temperature state:

- Record the temperature state of the vehicle power train at the beginning of the test and make an empirical correction to the observed data to predict the Federal test emissions level.
- Temperature condition the power train to the equivalent of the temperature state specified in the Federal test procedure.

In the first alternative, those engine variables which are known to affect warm-up emission characteristics would be measured and their values used to correct the measured emission levels to Federal cold-start values.

FIGURE 2-3
Hydrocarbon Emissions
Correlation of Individual Federal Cycles
New Jersey Test Program
43 Vehicles

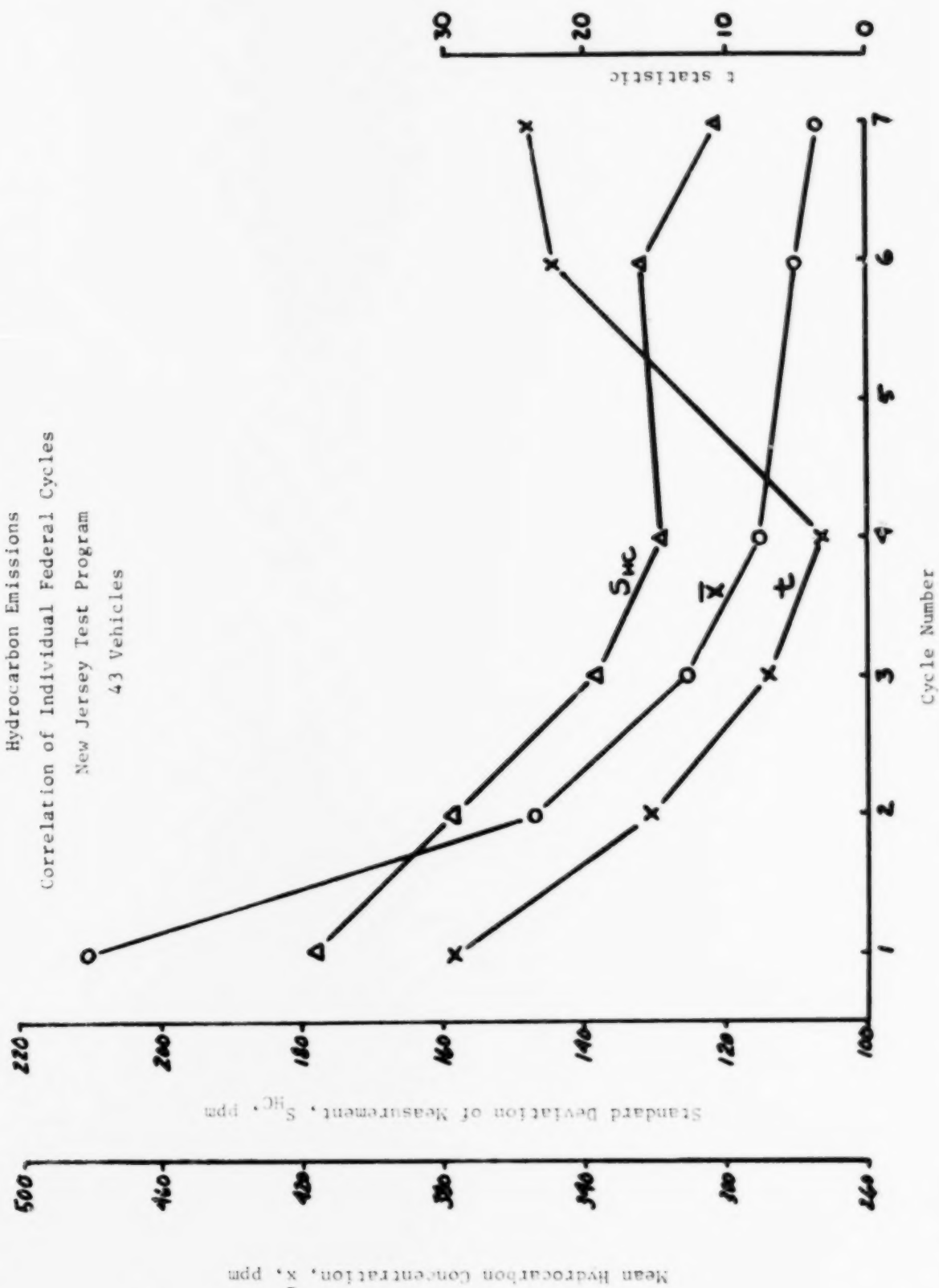
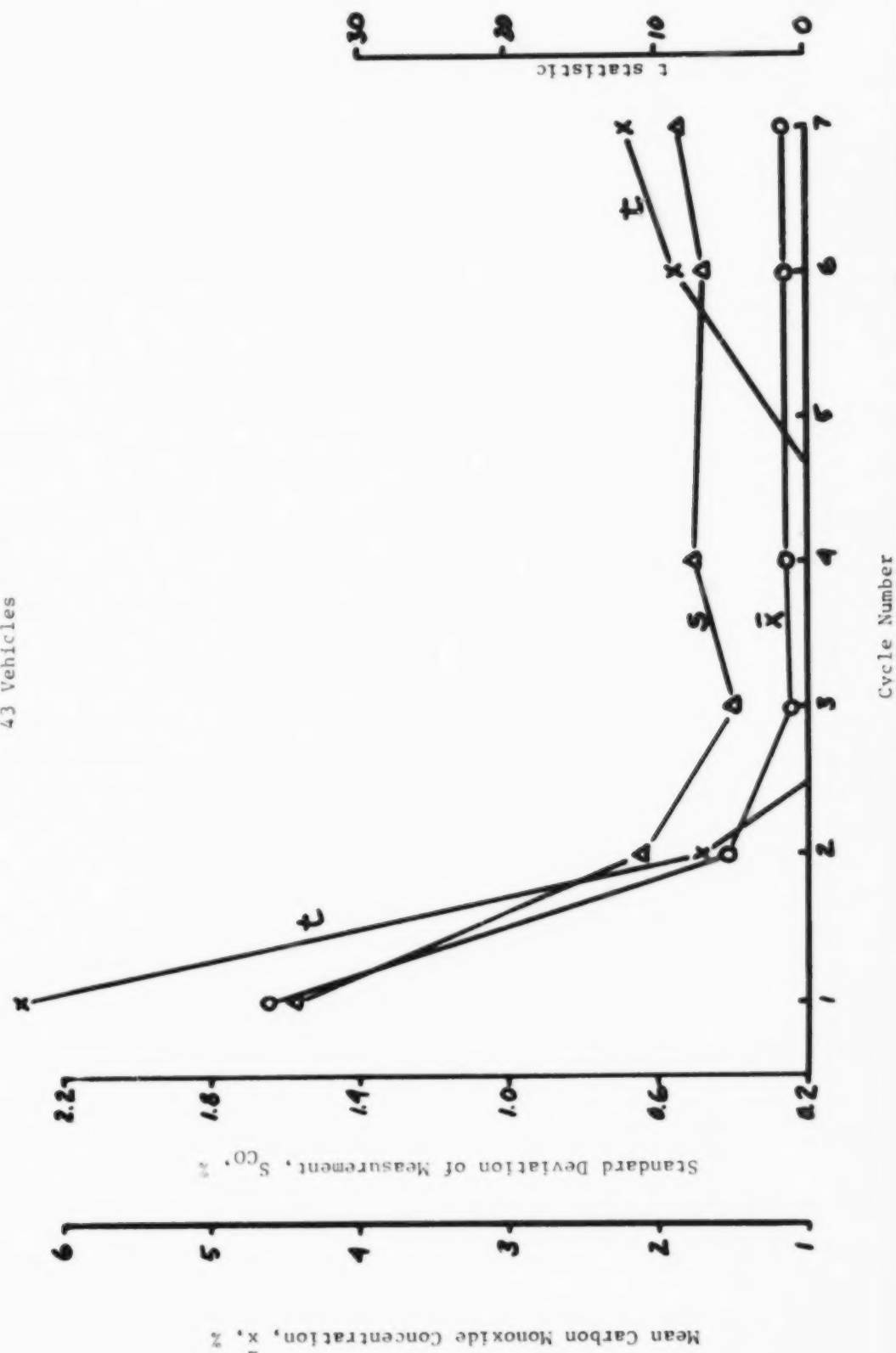


FIGURE 2-4
Carbon Monoxide Emissions
Correlation of Individual Federal Cycles
New Jersey Test Program
43 Vehicles



These variables would be measured and recorded in the field surveillance program before making emission measurements and empirically based weighting factors would be applied to the measured emissions to correct them to cold-start values.

Little reported data exist relative to the degree of correlation between emissions measured at arbitrary power train temperature states and those measured using the cold start Federal procedure. The best indication of the effects of temperature state on emissions may be had by comparing the so-called hot cycle emissions measured at block water temperatures in the range of 180-210°F with the full Federal procedure.

A correction factor is defined as the average ratio of individual vehicle hot cycle emissions to their Federal composite emissions.

$$K = \frac{1}{N} \sum_{i=1}^N \frac{(e_{\text{Fed}})_i}{(e_{\text{hot}})_i} \quad (2-1)$$

These correction factors are summarized in Table 2-2 for a number of vehicle model/years. These data were abstracted from the California ARB program, and a TRW analysis of the EPA 1968 surveillance data, Reference 2. As can be seen, differences exist in the correction factors and their standard errors across manufacture and model year. The correction factors for hydrocarbon emissions tend to be small, having a range of 1.06 to 1.20. Carbon monoxide correction factors and their standard deviation are significantly larger ranging between 1.27 to 1.44 and 0.39 to 0.87, respectively. These corrections are essentially equivalent to those required to predict Federal test emission levels from measurement made on a warmed-up vehicle.

The major unknown in the development of a short-duration emissions test procedure is the degree to which a vehicle power train must be temperature conditioned to provide an acceptably high correlation between emissions measured by the short procedure and the Federal test procedure. The only reported data bearing on temperature conditioning is that of Mick, et. al., Reference 3. Their data, Figure 2-5, indicate that

TABLE 2-2
HOT-TO-FEDERAL CYCLE CORRECTION COEFFICIENTS

<u>EMISSION</u>	<u>SAMPLE POPULATION SIZE</u>	<u>MEAN RATIO ΣCOLD/HOT/N</u>	<u>STANDARD DEVIATION</u>	<u>REFERENCE</u>
HC	1966 Chrysler 22	1.113	0.083	CARB
	1966 GM 28	1.156	0.140	CARB
	1966 Ford 24	1.197	0.208	CARB
	1968 HEW 200	1.060	-	HEW
	1968 HEW 400	1.055	-	HEW
CO	1966 Chrysler 22	1.412	0.61	CARB
	1966 GM 28	1.443	0.874	CARB
	1966 Ford 24	1.344	0.392	CARB
	1968 HEW 200	1.27	-	HEW
	1968 HEW 400	1.30	-	HEW

CARB - California Air Resources Board
HEW - Dept. of Health, Education and Welfare

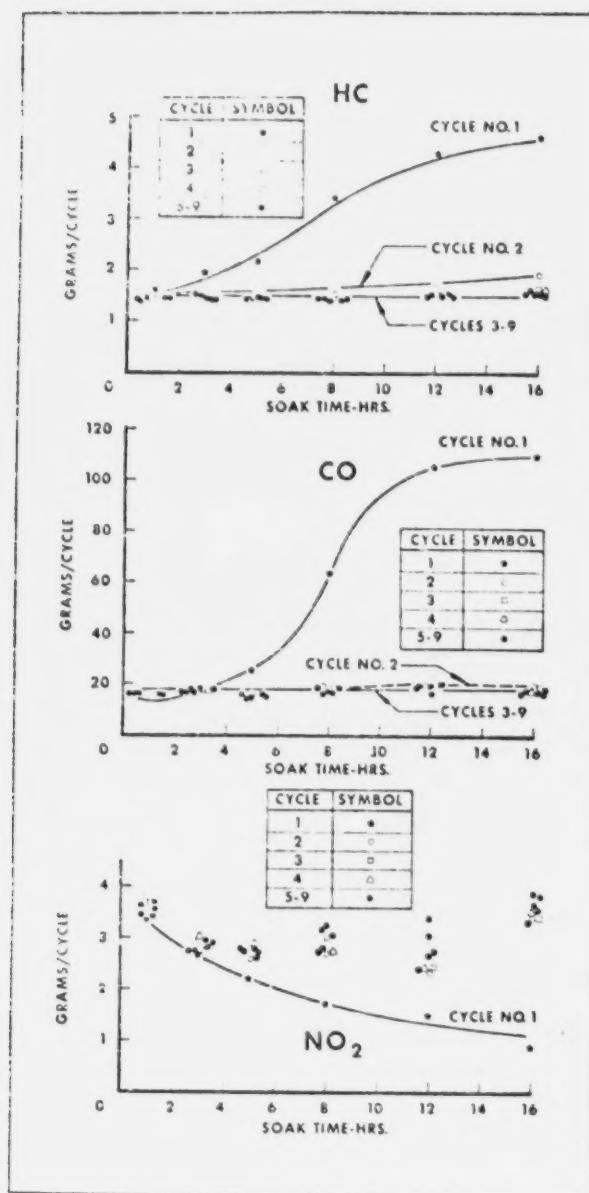


FIGURE 2-5
INFLUENCE OF COLD
SOAK DURATION ON CYCLE MASS EMISSIONS
REFERENCE 3

vehicles must be allowed to cool naturally for approximately 8 hours before their measured mass weighted emissions approach those determined using the Federal test procedure. Temperature data were not presented to describe the state of the power train.

It is obvious from these results that the development of an emissions test procedure of significantly shorter time duration will require procedures for accelerating the cooling of vehicle power trains. It also was concluded that additional experimental data would be required to determine more completely the relationship between key power train temperatures and emissions. Accelerated temperature conditioning experiments, therefore, were conducted on eleven power trains which are representative of exhaust emission control devices and engine cubic inch displacements in current service. The experimental program and its results are presented in Section 3.0.

Effect of Replication on Measurement Precision

The effect of cycle replication is to increase the precision with which the mean emissions for a single vehicle are measured. The significance of replication may be more fully appreciated by constructing a model based on the statistics of small samples. Let it be assumed that it is required to describe the emission level of a single vehicle using a data set free of temperature bias error. An estimate of the standard error is assumed to be known and a value for the confidence level selected. A "t" statistic will be used which is the two-sided value of Student's "t" based on N-1 degrees of freedom (cycle replications) at the selected confidence level. The statistic $t/\sqrt{N}$ is the factor which, when multiplied by the estimate of the standard deviation, S, estimates the confidence band for the mean. The confidence band for the emission mean is then given by:

$$\bar{X} \pm \frac{t}{\sqrt{N}} s \quad (2-2)$$

This relationship is graphically illustrated in Figure 2-6.

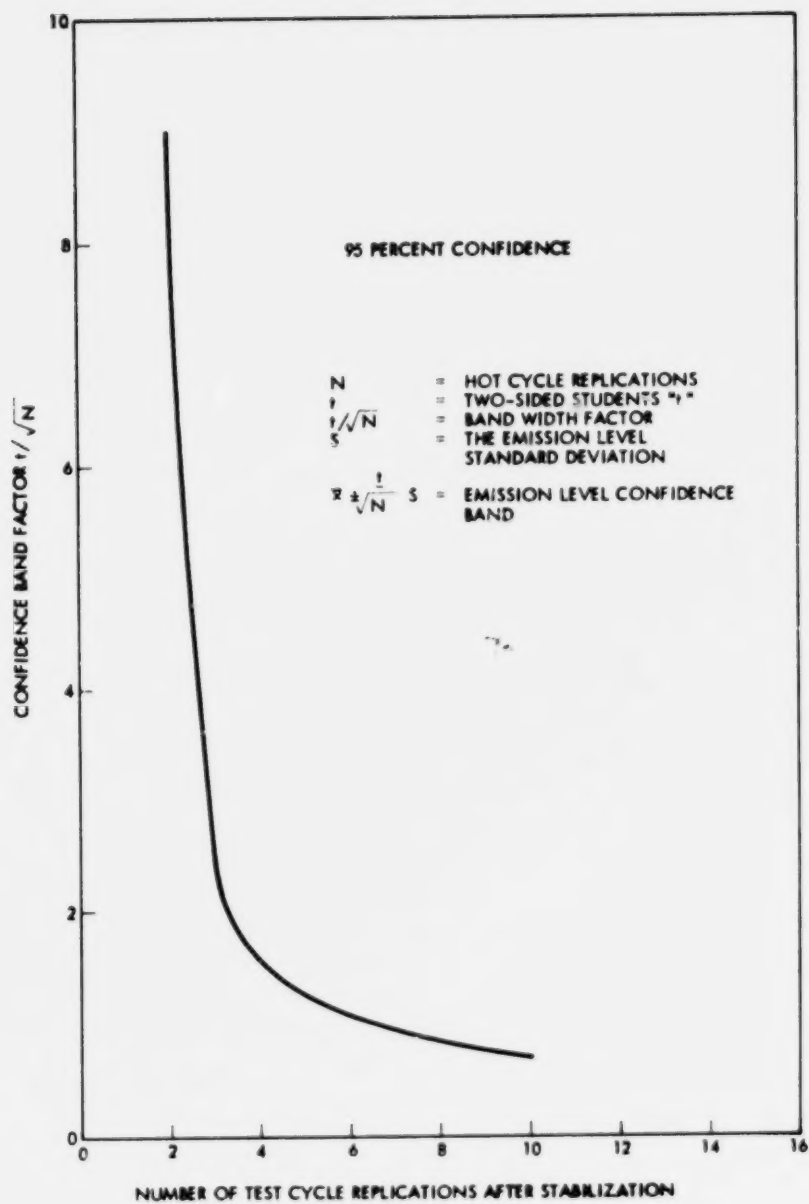


FIGURE 2-6
EFFECT OF HOT CYCLE REPLICATION ON PRECISION

It is seen that there is a major decrease in the confidence band factor between $N = 2$ and $N = 3$, and then a progressively smaller decrease between successive replications. A point of diminishing returns is reached at about $N = 6$. Thus, an economically optimum test procedure probably involves using between three and six replications of the stabilized hot cycle, depending, of course, on the relative costs of adding cycles versus the value of reducing the confidence band width. It would be difficult, however, to envision a case where it would not be cost-effective to utilize an emission mean based on at least three replicated stable cycles.

Intra- and Inter-Laboratory Measurement Errors

Within (intra) and between (inter) laboratory test and instrument controls are extremely important to assure measurement precision and accuracy. Precision is defined as the ability of a measurement system to repeat itself when given the same input emission concentration while accuracy is defined as an error which occurs when the instrument consistently measures a known input emission with a bias.

Intra-laboratory measurement errors most commonly occur because of:

- Poor calibration technique
- Inadequate instrument system maintenance
- Arbitrary or inconsistently applied quality control procedures
- Poor instrument sensitivity and/or response

Inter-laboratory measurement errors occur because of:

- Different instrument system configurations
- Bias errors in calibration gases
- Any of the intra-laboratory type errors when consistently repeated.

Intra Laboratory Test Control

Procedures used by laboratories conducting surveillance programs often involve somewhat arbitrary criteria for deciding when to:

- Reject a vehicle test

- Maintain or recalibrate instrument systems at frequencies greater than those prescribed by the Federal test procedure.

Some criteria used to reject a vehicle test are poor duplication of the driving cycle, anomalous pre- or post-test instrument span checks, and indications of a malfunctioning vehicle exhaust system such as might be revealed by the dilution correction factor.

With regard to test cycle duplication, it would seem important to have a permanent copy of the driving cycle and to use significant discrepancies in the more important cycles as a basis for test rejection. For example, the last two cycles of the Federal procedure are the more heavily weighted and, therefore, should be required to have good cycle-to-cycle correlation with the driving trace.

The span check data developed when setting the zero and full-scale deflection of NDIR instruments can be used to determine the need for instrument repair and recalibration and as a basis for rejecting test results. A mid-scale span check, for example, could be used for quality control based on either of the following tests:

- Test each individual mid-span point against the standard error for the calibration curve
- Construct a two-sided control chart and cumulate mid-span data to establish out-of-control limit conditions.

The first test proposed would provide a criterion for rejecting an individual emissions test based on a hypothesis test that the span check was or was not part of the calibration data set. The two-sided control chart would be used as a guide for determining longer term deterioration and preventative maintenance requirements associated with the optics of the instrument.

Both procedures require an accurate estimate of the calibration curve and its variance. After experimenting with several functional forms to describe the calibration curve, the equation describing the law of optical attenuation, Beers Law, was selected and used to develop calibration curves. A nonlinear regression of calibration data (10-15 points) then can be used to establish a standard error of the estimate with loss of only two degrees of freedom. An application of this procedure is presented below.

Beer's Law can be written

$$K_1 D = 1 - e^{-K_2 C} \quad (2-3)$$

where

D = strip chart deflection, divisions

C = emission concentration, ppm or percent

K_1, K_2 = constants characteristic of the emission gas

Calibration curves fitted with Equation 2-3 are shown in Figures 2-7, 2-8, and 2-9. Most emissions measurements are made at one end of the curve and, therefore, the curve fits were designed to be most accurate within that range. The universal adoption of this approach would standardize the procedure for converting instrument output voltage (deflection) to engineering units (ppm or percent).

In addition to the above, a quality control chart of the gain required to set full scale would be helpful to establish maintenance criterion for the electronic components of the system.

Inter Laboratory Control

Emissions measurements occasionally have been shown to differ significantly between test laboratories. Two methods are commonly applied to quantitize these differences. These are across laboratory analyses with an:

- Identical gas sample
- Emission stable test vehicle on which the Federal procedure is performed.

In the former approach, typified by the Scott Research Laboratories (SRL) Cross-Reference Check, samples of known composition are circulated to subscribers. Statistical attributes of the sample are developed for each instrument type (CO, CO₂, high and low HC). Figures 2-10 and 2-11 show typical results for CO and HC from the SRL Cross-Reference Check over the period 1968-1970 for all subscribing laboratories. The standard error for

Figure 2-7. Standard CO & CO₂ Calibration NDIR Instruments

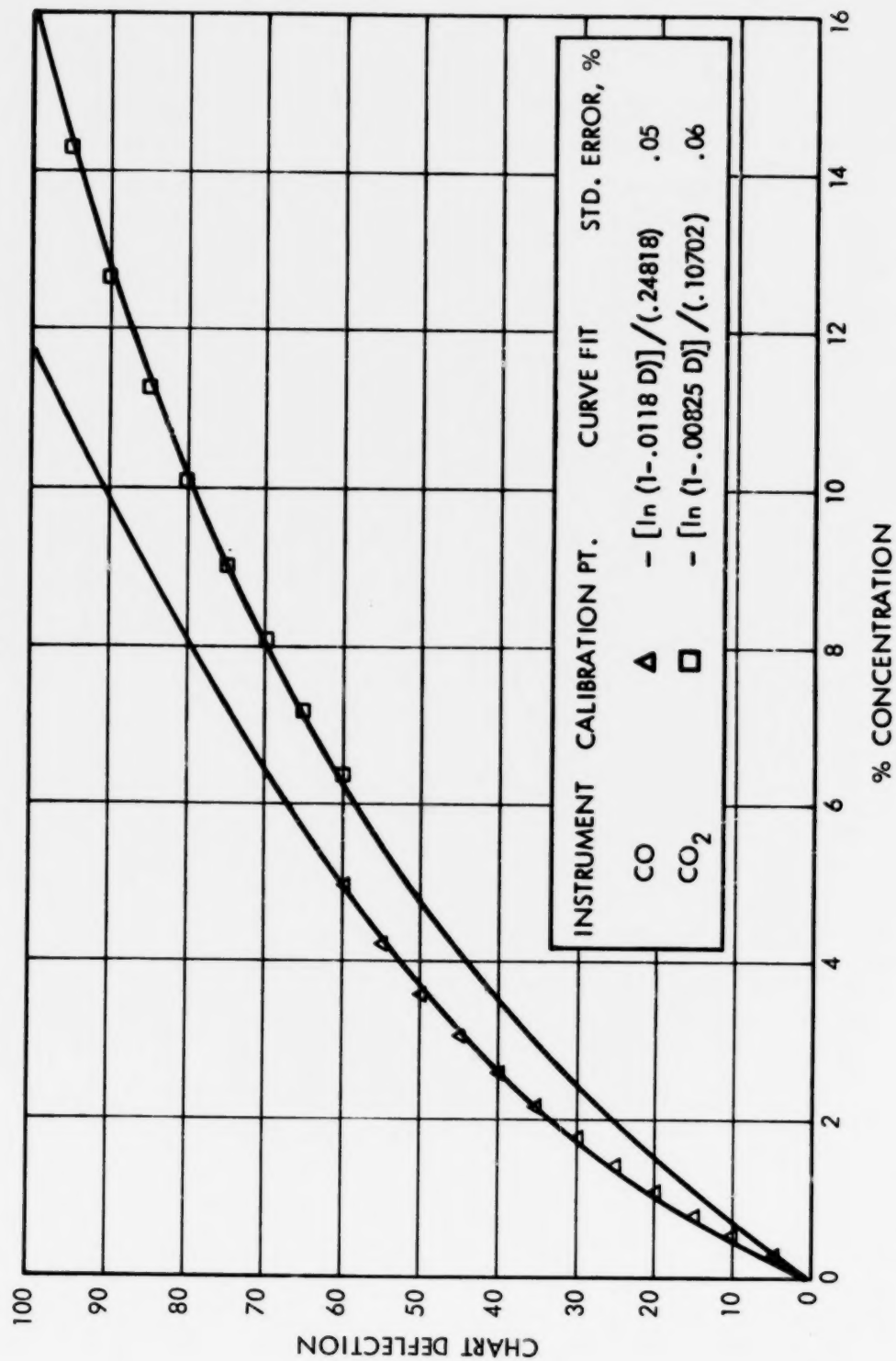


Figure 2-8. Standard LHC & HHC Calibration NDIR Instruments

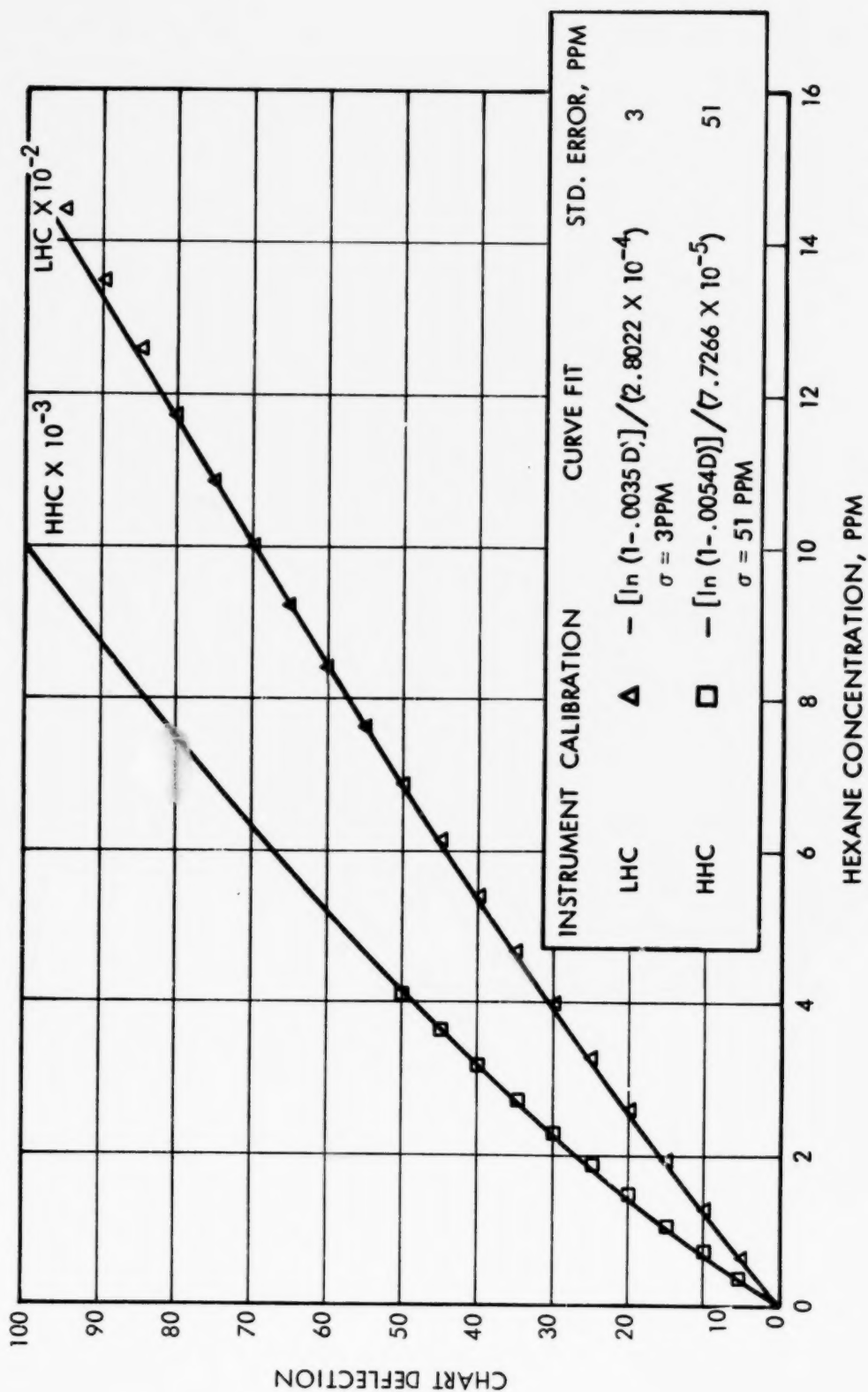


Figure 2-9. Standard NO_x Calibration NDIE Instruments

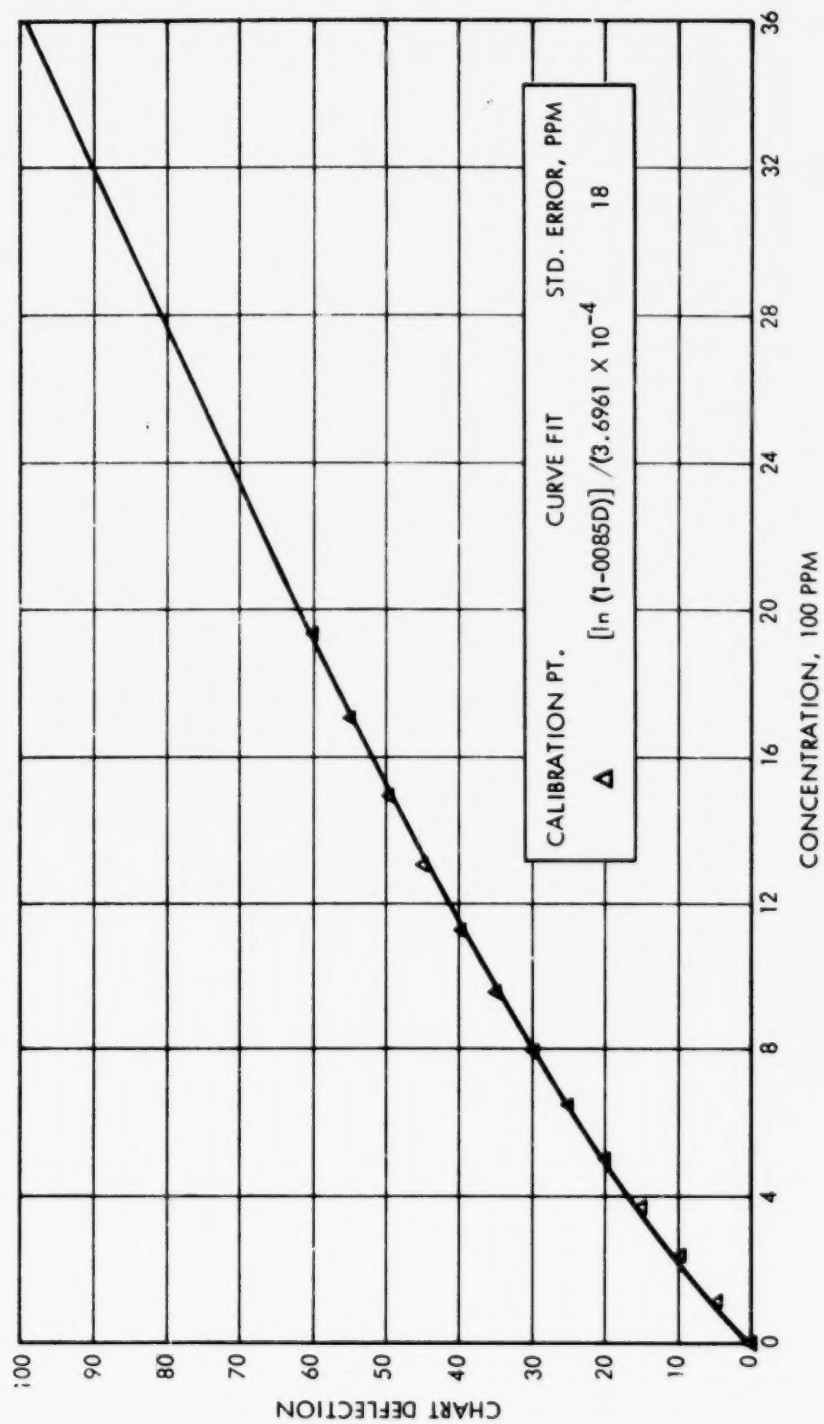


Figure 2-10. SRL Cross Reference Check Statistical Data Summary
HC NDIR Type Instruments (1968-1970)

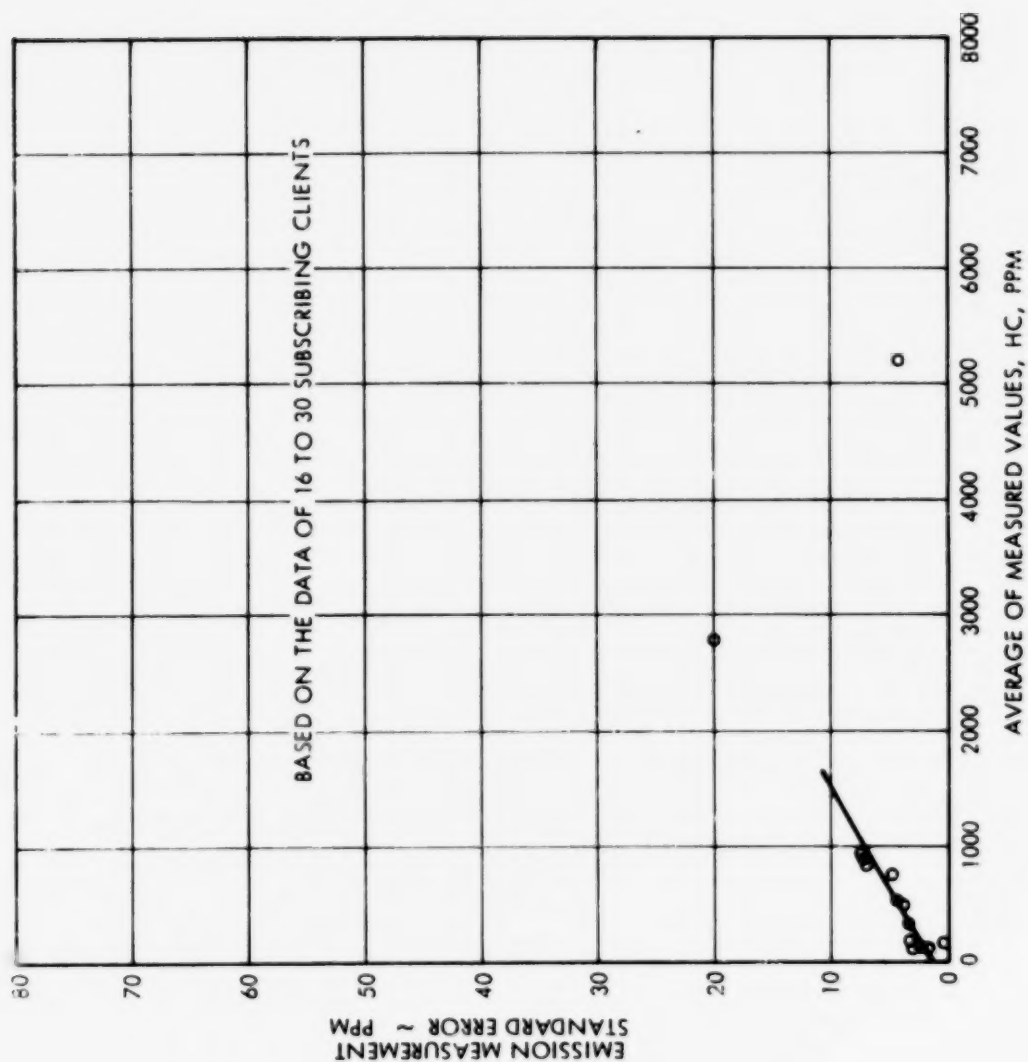
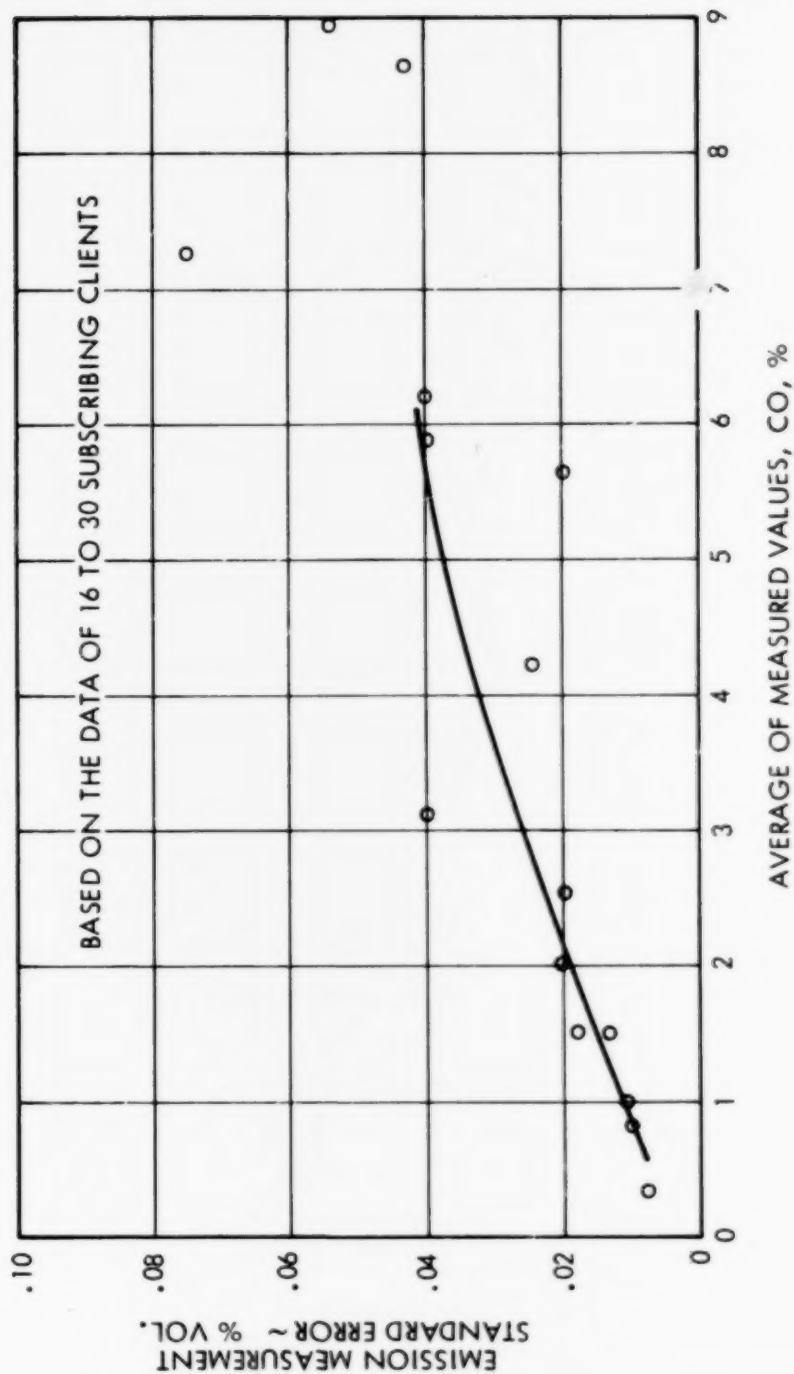


Figure 2-11. SRL Cross Reference Check Data Statistical Summary
CO NDIR Type Instruments (1968-1970)



the unknown is plotted against the average value of the unknown. The standard error is seen to be a strong function of the absolute emissions value. For the range of concentrations most heavily weighted in the Federal procedure, errors (one-sigma) of 3 to 5 ppm and 0.02 to 0.04 percent are indicated for HC and CO, respectively. These errors are surprisingly low and equivalent to that of the instrument system. It should be noted that even though 67 percent of the facilities fall within this error band, the one or two laboratories at three-sigma will have significant bias relative to the other laboratories. This results in a significant error when testing classes of vehicles for compliance at different laboratories where class/year variances are small relative to the total population. It would, therefore, seem pertinent when performing surveillance for compliance that the samples for various vehicle engine families be split equally among the laboratories conducting the program. This would avoid selectively biasing emissions measurements which would unduly penalize or favor a particular engine class. When only one laboratory is conducting a compliance program, considerably more care must be taken in controlling inter-laboratory bias errors. At a minimum, it is recommended that this facility not fall outside of the one-sigma range of similar laboratories.

The test of inter-laboratory differences using samples of known composition suffers from the disadvantage that it does not give a measure of instrument response or HC hang-up such as would occur in an actual Federal test. A procedure for correcting these deficiencies is to trailer an emissions stable vehicle to the laboratory. Because of high within-vehicle variability caused by instability of engine deposits and adjustments, this approach is not generally recommended. For example, within-vehicle emissions variability as measured on a single test lane using the hot cycles indicates a 24 ppm standard error (see Section 4.0). This is significantly larger than the 5 ppm error measured by the cross-reference check method. However, instrument systems tested in parallel with an identical vehicle emissions test would be highly meaningful. This approach would have greatest utility within a single facility where multiple test lanes were operational.

2.2.2 Vehicle Selection and Acquisition

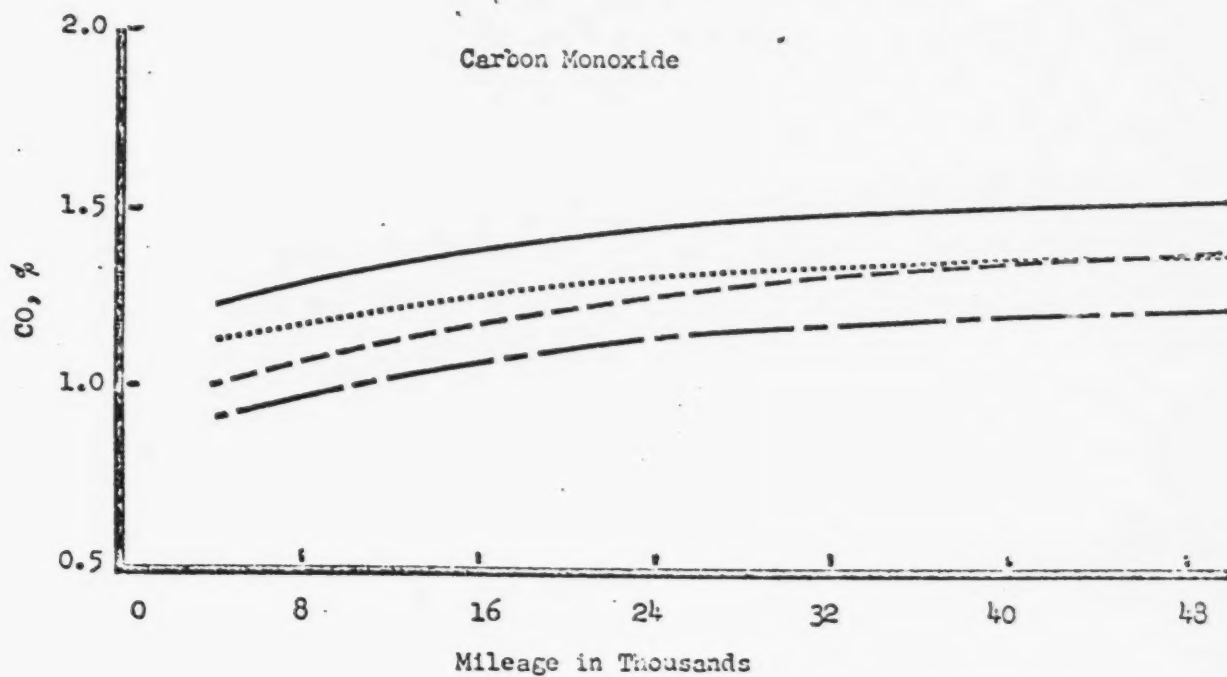
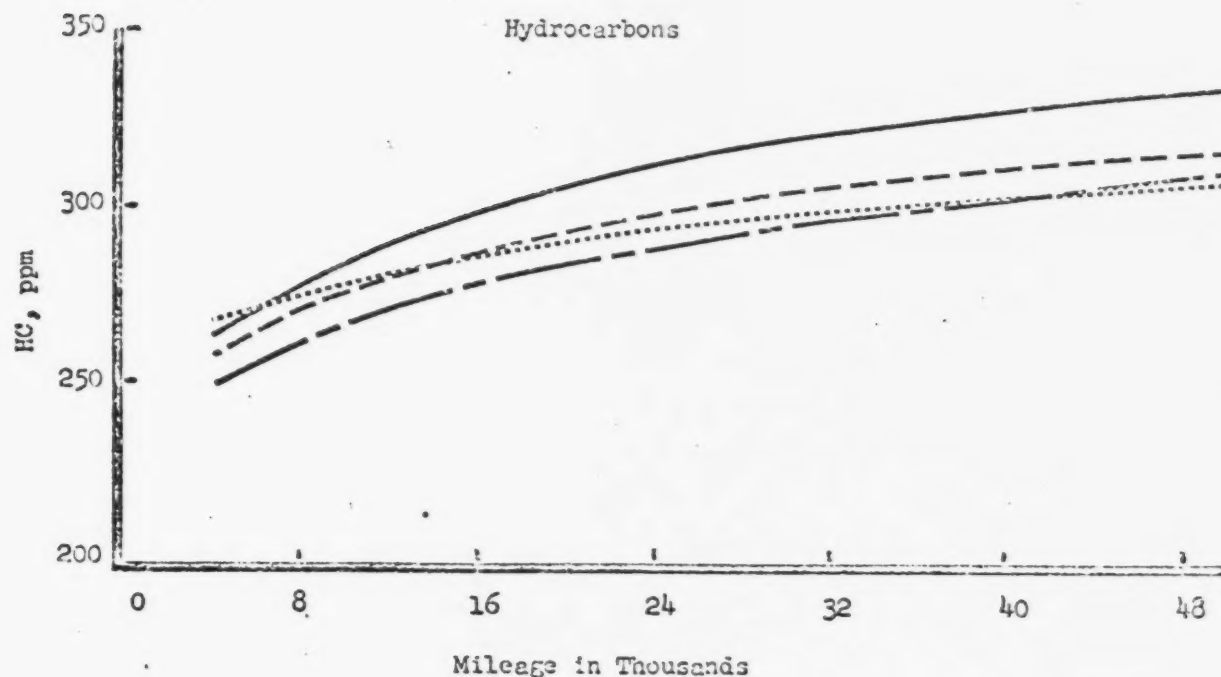
The method used to obtain a sample of test vehicles from a general population is critical in making an accurate prediction of regional vehicle emissions. The vehicle sample must reflect all essential attributes of the population to which the test results are to be applied. This may impose difficulties in acquiring vehicles and have an important impact on surveillance program cost. Vehicle attributes shown to be of importance in a selection process are:

- Power train characteristics (cubic inch displacement, number of cylinders, transmission type)
- Make/model/year of the vehicle
- Accumulated mileage
- Maintenance frequency and extent to which an engine is tuned to manufacturer's specifications.

Power train characteristics are known to have a significant effect on emissions. For example, manual transmissions have higher emissions in otherwise identical power trains because of the engine transients introduced at each shift point. It is important that power train types be accurately reflected within model years although the particular chassis within which they are installed may be of lesser importance if the vehicle sample reflects a weight distribution similar to the population. Vehicle model/year is an extremely important attribute because the performance of exhaust emission control devices have and will continue to improve. This is dramatically shown in published California Air Resources Board data abstracted from Reference 4 and presented in Figure 2-12. The significance of mileage within one make/year is also demonstrated. Obviously, the vehicle sample mileage distributions should be compared against those of the population at the point in time when emissions to the atmosphere are to be estimated.

The frequency, quality, and extent of maintenance is probably the most difficult population attribute to match. The work being performed under APRAC CAPE-14 and CAPE-15 on procedures for inspecting and maintaining those power train components which have strong influences on emissions has provided some relevant data. In this program, both the frequency and extent of engine

FIGURE 2-12
 Exhaust Emissions vs. Mileage
 1966-1969 Model California Automobiles. Total Population
 Hot Start Data
 Reference 4



1966 ——— 1967 1968 - - - - 1969 - . - . -

and control device maladjustments, as well as the effects of these maladjustments on emissions were evaluated. The experimental data indicate that the following maladjustments are of importance:

- Ignition misfire
- Carbon monoxide concentration at engine idle speed
- Air pump malfunction (on vehicles so equipped)
- Basic ignition timing
- Engine idle speed

Distribution functions for these maladjustments are shown in Table 2-3. Of these maladjustments, idle carbon monoxide concentration and ignition misfire have by far the greatest effect on population emissions. Therefore, it is concluded that the test sample must match the reference population at least with respect to the important attributes of vehicle mileage, idle CO, and percent engine misfire.

The distribution of these attributes in the sample should be compared against the population distribution. Significant nonconformance of these distributions should be corrected by:

- Selecting additional vehicles with malfunctions which will result in an improved sample match
- Correcting the emissions levels using empirically derived influence coefficients and population distribution functions.

The former procedure is straightforward; the latter procedure presumes empirical relationships have been established experimentally.

Various sources are available from which vehicles may be acquired for surveillance testing. Vehicle sources can be classified into three main categories:

- Leased vehicles
- Borrowed public vehicles
- Borrowed private vehicles

TABLE 2-3
TYPICAL ENGINE MALFUNCTIONS AND ADJUSTMENTS AFFECTING
VEHICLE EMISSIONS
(Engine Modification Emission Controls)

Engine Malfunction	Mean Population Value	Standard Error About Mean	Emission Sensitivity Δ Emission / Δ Malfunction		
			HC (ppm)	CO (percent)	NO (ppm)
Idle CO	2.77%	2.71	-17	0.37	-8.18
Timing, degree	0.7	5.8	7.2	-	38
Idle Speed, rpm	6	95	-5.3	-	-
Air Cleaner, plugged/open	6.0%*		-28	-0.85	113
PCV, plugged/ open	12.0%*		-57	-0.51	208
Misfire	4.4%*		99	-	-

*Percent of population having malfunction

Obtaining vehicles from a combination of these sources may be attractive for specific surveillance strategies and objectives. Selection of a vehicle source is dependent on which the following criteria dominate:

- Requirement to retain the vehicle for long periods of time, i.e., 24 hours or more
- Proximity of test site to the source of vehicles
- Requirement to discern small differences in emissions brought about by abatement policies
- Necessity to duplicate an actual population distribution (make/model/year/mileage/use).

The advantages and disadvantages of using vehicles in each category are summarized in Table 2-4. As can be seen, all sources have limitations. Although the use of private vehicles is the best method for matching vehicle populations, the cost of acquiring private vehicles for long-term retention will probably be higher than from other sources because of costs associated with identification, scheduling, and providing loan cars. The use of private vehicles is extremely attractive when a short duration emissions test is acceptable and where vehicle inspection systems (emission or safety) are already in existence since virtually any registered vehicle is available. Data can be obtained at selected inspection lanes in which additional equipment is installed to perform the requisite emissions test procedure.

Based upon the direction of the CAPE-13 steering committee, surveillance cycles to be considered in this project are limited to range from one hot 7-mode cycle to the full Federal test procedure. Variables to be manipulated include the number of test replications, degree of temperature conditioning, and method for acquiring test vehicles. Representative labor and vehicle retention times required to perform the emissions testing in a number of alternate ways are shown on Table 2-5. The following assumptions were involved in constructing this table:

- Fixed surveillance stations testing private vehicles will draw on vehicles within a 15-mile radius and require an average one-way trip of 10 miles--90 minutes are required for pick-up and return including wait time.
- Fixed surveillance stations testing rental vehicles are within 5 miles of the rental agency location--45 minutes are required for pick-up and return.

TABLE 2-4

VEHICLE ACQUISITION ALTERNATIVES

<u>Source</u>	<u>Advantages</u>	<u>Disadvantages</u>
Rental Agencies	• Reliable scheduling • Reliable historical records • Indefinite vehicle retention	• Moderate acquisition costs • Short fleet life for recall • Not typical of vehicles in use (driving & maintenance) • Limited ability to match populations
Private Owner - Short Retention (individual owner)	• Minimum acquisition costs • Representative population sample • Moderate fleet life for recall • Typical of in-use vehicles • Large sample sizes available • Compatible with vehicle inspection system	• Mobile laboratory a likely requirement • Requires truncated Federal Test because of limited vehicle retention
Private Owner - Long Retention (company vehicle fleets + individual owners)	• Representative population sample • Moderate fleet life for recall • Typical of in-use vehicles • Moderate sample sizes available	• High acquisition costs because of identification, scheduling and loan vehicle costs
Public Owner - (Federal and state fleets)	• Minimum acquisition costs • Moderate fleet life for recall	• Limited ability to match populations • Somewhat limited retention • Not typical of in-use vehicles

TABLE 2-5

SURVEILLANCE PROCEDURES LABOR AND TEST TIMES

Surveillance Station Type	Temperature Conditioning Treatment	Number of Cycle Replications	Vehicle Acquisition Source	Time-Min for Roundtrip	Temperature Conditioning Time-Min	Emission Test Time Min	Total Labor Time-Min*	Total Vehicle Retention Time-Min
Fixed	None	1	Rental	45	0	7	59	52
		2			0	9	63	54
		3			0	11.5	63	56.5
		Full, 7-9			0	17-22	79-89	62-67
Fixed	Hot	1	Private	90	2	7	106	99
		2			2	9	110	101
		3			2	11.5	114	103.5
		Full, 7-9	Private	90	120	17-22	124-134	297-302
Mobile	Hot	Full, 7-9	Rental	45	720	17-22	79-89	782-787
		1	Private	0	1	7	15	8
		2			1	9	19	10
		3			1	11.5	24	12.5

*Includes 5 minutes of pre/post vehicle preparation

- Forced temperature conditioning to a state approaching the Federal test requirements can be accomplished in 2 hours.

The labor and vehicle retention times associated with a mobile station conducting shortened emission test procedures are significantly lower than any other procedure. A decrease in vehicle retention times exceeding 50% of that required for testing using the full Federal procedure can be obtained by forced cooling of the vehicle power train to cold-start temperature.

Comparing fixed and mobile station total labor times indicates even more substantial reductions in costs. A direct labor or inconvenience time is charged to vehicle acquisition for fixed sites as some cost is incurred for vehicle transport whether the owner drives his vehicle or it is picked up. Mobile stations are assumed to be sited so as to avoid vehicle transport. For example, stations would be sited in public or industrial parking lots. Since the vehicles were brought to these sites for other purposes deemed important to the owners, no direct acquisition costs are assumed.

Identification of specific vehicles to be tested and the liaison necessary to obtain the vehicles must be performed regardless of the method of acquisition. This cost is assumed to be fixed and to a first-order approximation insensitive to site configuration.

It would appear that accelerated temperature conditioning in mobile surveillance stations sited in industrial parking lots may substantially decrease both direct labor and vehicle retention costs. Alternatively, a program in which vehicles are tested in their "as-received" condition or with temperature conditioning to a hot-start state appears to be extremely cost effective. These two approaches have been selected for detailed evaluation in Section 5.0.

3.0 DEVELOPMENT OF DATA FOR THE SURVEILLANCE SYSTEM MODEL

Equipment and procedures to be considered when planning a vehicle emissions surveillance program have been described in Section 2.0. These general considerations have defined a need for specific data to be used in modeling a surveillance program. This section presents a discussion of the experiments and analyses used to develop the required data to describe:

- Emissions test procedures
- Operational procedures
- Equipment and facilities

3.1 Emissions Test Procedures

The procedures for which data must be developed to describe an emissions surveillance program are:

- Power train temperature conditioning
- Driving cycle replication
- Vehicle sample selection
- Instrumentation

Although intra- and inter-laboratory differences are important considerations, their indicated error impact on predicting emissions to the atmosphere is small and can be kept under control using the techniques discussed in Section 2.0. The acquisition and/or development of the data for the above test procedure models are discussed below.

3.1.1 Power Train Temperature Conditioning

Two approaches can be taken to establish the emission levels of vehicles without resorting to the 12-hour cold soak period prescribed in the Federal test procedure. Either empirical relationships can be developed and used to correct the emissions of a power train measured with an arbitrary initial temperature state (including a stabilized hot start) to that emission level which would have been determined by a cold-start Federal test or accelerated power train cooling can be used to produce a temperature state approaching cold-start conditions and a

pseudo-Federal test performed. As was noted in Section 2.0, experimental data were not found in the literature relating emissions to the initial temperature state of the power train nor were data found describing procedures for accelerating engine cool-down to an ambient temperature state. Since vehicle acquisition and storage costs can be cut significantly if power train temperature conditioning times can be reduced, an experimental program was conducted to develop these data. Two primary objectives were to be achieved:

- Definition of the sensitivity of emissions as measured by the full Federal procedure to key power train temperature states
- Selection of procedures for accelerating the power train cooling rate.

The temperature conditioning experiment and its results are described in this section.

Experimental Approach

Several criteria were used to select accelerated cool-down procedures. These were:

- The car must be restored to the condition in which it was submitted, including the block cooling fluid
- Cool-down rates must not be so severe that thermal shock will result
- The procedure must be simple and reproducible.

Forced cool-down methods satisfying the above criteria were screened in order to select the most appropriate procedures for the temperature conditioning test. The six techniques screened were:

- (1) Forced air cooling using approximately 30 mph flow through the radiator
- (2) Forced air cooling using approximately 30 mph flow through the radiator and across dry ice bags
- (3) Same procedures as (1) while starting the engine intermittently to circulate coolant until the thermostat closes
- (4) The same procedure as (3) except that in addition a water spray was directed onto the bottom of the engine and transmission housing
- (5) Removal of the cooling system thermostat and installation of external coolant circulating pump. Circulate coolant and use 30 mph forced air cooling through radiator

- (6) The same procedure as (5) except that in addition a water spray was directed onto the bottom of the engine and transmission housing.

During the experiments the following temperatures were monitored:

- Choke (on or near the bimetallic spring)
- Carburetor bowl temperature
- Crankcase oil temperature
- Transmission oil temperature
- Water temperature: a) at outlet from block
b) at outlet from radiator
- Radiator temperature (leading edge of fins)

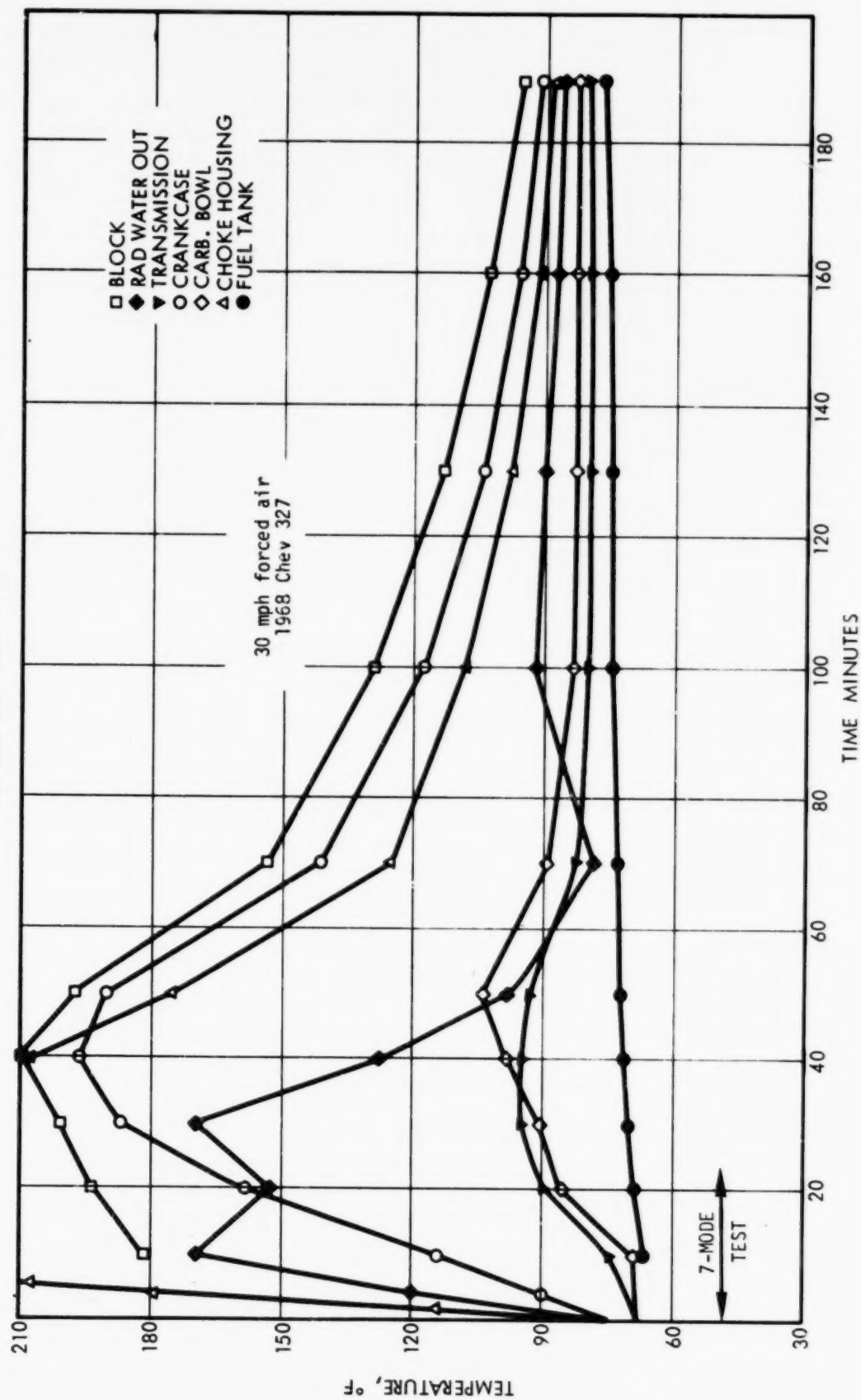
The candidate cool-down procedures were evaluated by first measuring the emissions of the test vehicle using the cold start Federal 7-mode, 7-cycle test. After applying the cool-down procedure until block water outlet temperature reached 110° , a second 7-mode, 7-cycle test was run. The cool-down procedures were again applied until block water outlet temperature reached choke closure temperature and a third 7-mode, 7-cycle emissions test was run. Typical temperature responses of power trains to these procedures are presented in Figure 3-1.

The data thus collected were analyzed and the following conclusions were reached:

- Although the measured power train temperatures vary from each other considerably during engine operation, key temperatures approach the block water temperature during cool-down.
- Circulating water in the radiator and block (with or without the external spray) was significantly more effective in closing the choke than any of the other treatments investigated.
- Using dry ice or the under-car spray did not appreciably improve the cool-down time for either the forced air or the circulating coolant treatments.

The six techniques screened in the experiment just described were reduced to the following two procedures for evaluation in an 11-car temperature-conditioning test:

FIGURE 3-1
TYPICAL TEMPERATURE RESPONSE TO ACCELERATED
TEMPERATURE CONDITIONING



- (1) Force air at approximately 30 mph through the radiator and over the engine.
- (2) Circulate coolant with thermostat removed through the block and radiator using an external coolant pump. Force air at approximately 30 mph through the radiator and over the engine.

The 11 power trains tested were selected on the basis of a best compromise between the type of emission control system, manufacturers percent of sales, and the engine cubic inch displacement. Significant attributes of these power trains are presented in Table 3-1.

Procedure (1) was evaluated on each vehicle using application periods of both 2 and 3 hours. Procedure (2) was evaluated for application periods of 0.5 and 1 hour.

Figure 3-2 shows the 3-day test procedure which was performed on each vehicle. The first day was devoted to preparation of the vehicle for test. This preparation included an inspection to evaluate the general maintenance state of the vehicle, correction of any major discrepancies, instrumenting the vehicle for the required temperature measurements and setting up the dynamometer for the tests.

The second test day began with a Federal cold start test. This was followed by a 0.5 hour forced cool-down during which the coolant was circulated through the radiator and block (thermostat by-passed) and air was blown through the radiator. A Federal test (pseudo-cold start) was then run to evaluate the effectiveness of the procedure. Subsequent forced cool-down treatments involved 1 hour and 0.5 hour application periods with the Federal test procedure run immediately following each forced cool-down.

The third test day was similar to the second except that only forced air cooling was used with treatment times of 2 and 3 hours.

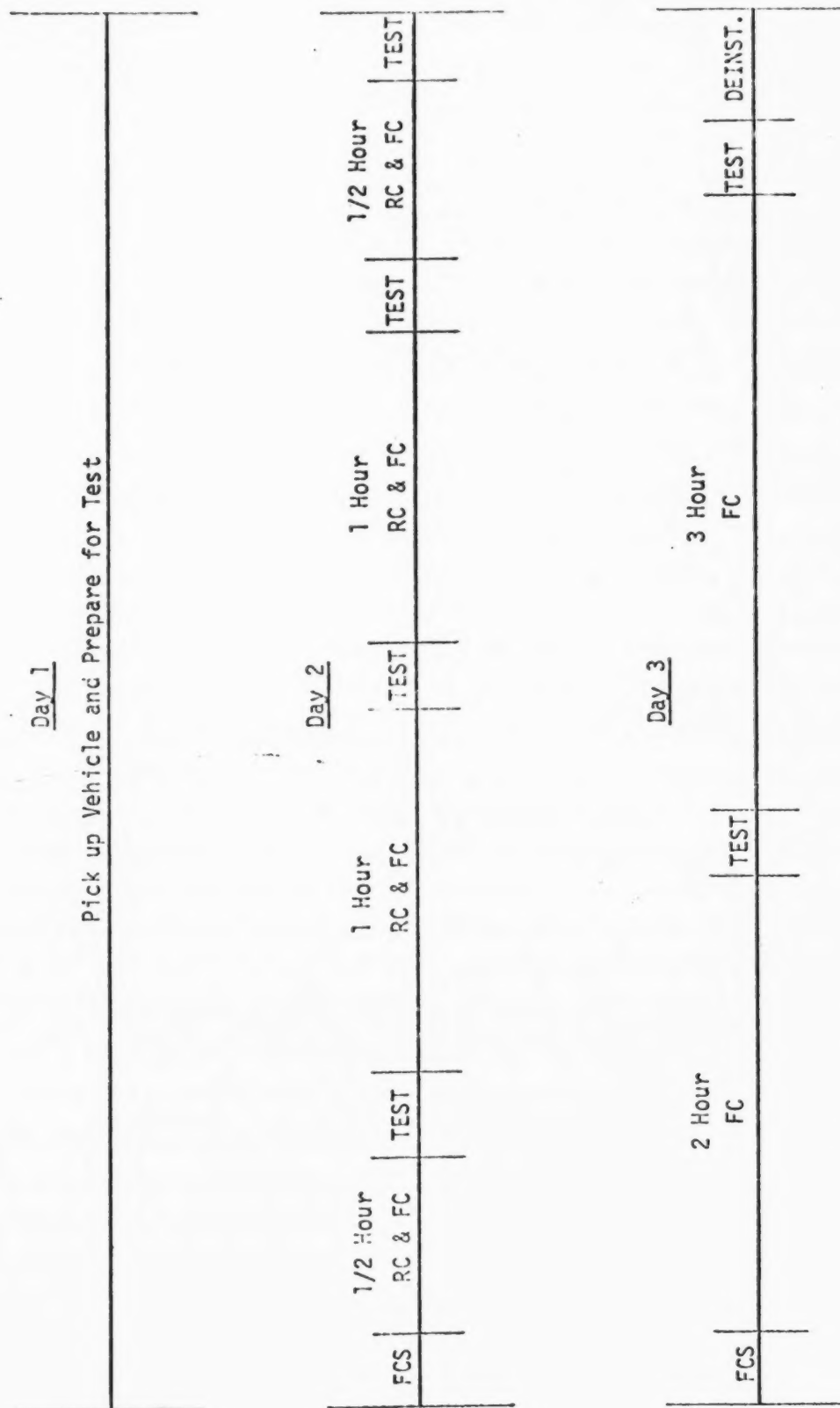
Figure 3-3 illustrates the test set-up used for the temperature conditioning tests. An external coolant pump and gate valves were added to the normal coolant system configuration and the thermostat was moved from its normal location in the block and installed in the exterior line. This test set-up was made to facilitate the change-over from a thermostat controlled, internal coolant pump system required for the Federal test to an

TABLE 3-1
TEMPERATURE CONDITIONING VEHICLES

TEST NO.	MODEL / YR	EMISSIONS CONTROL	CID	MILEAGE
401	68 PLY	EM	318	23,300
402	68 CHEV	EM	327	26,400
403	66 CHEV	AIR	283	40,500
404	67 FORD	AIR	390	58,400
405	69 FORD	EM	302	10,300
406	68 FORD	EM	390	15,000
407	66 DODGE	EM	383	56,600
408	66 FORD	AIR	200	30,800
409	68 BUICK	EM	430	4,000
410	68 FORD	AIR	302	32,400
411	69 PLY	EM	225	14,700

AIR = air injection reactor
EM = engine modification

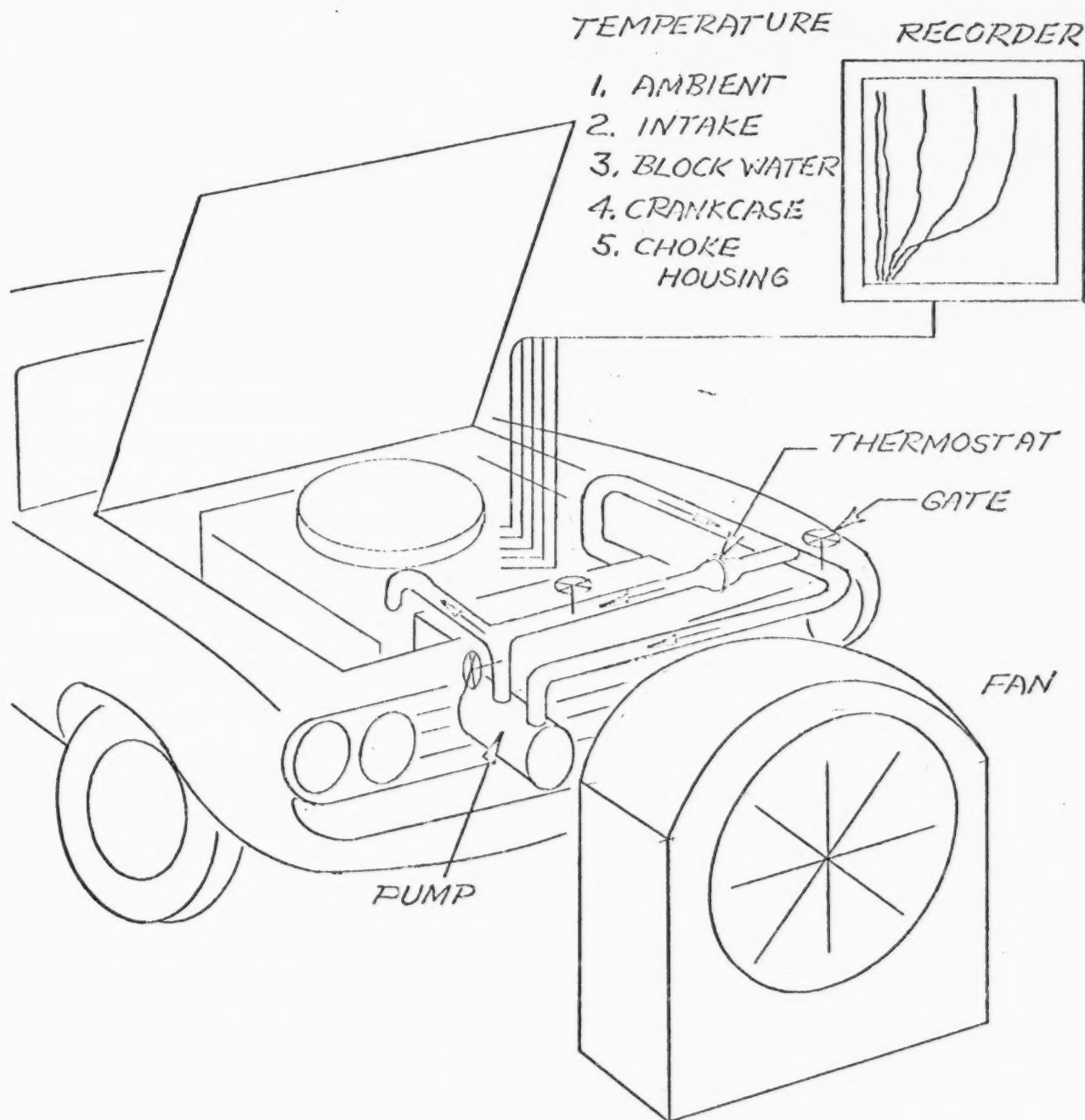
FIGURE 3-2
TEMPERATURE CONDITIONING EXPERIMENT PROCEDURES



RC = recirculating block coolant
FC = forced convection with 30 mph fan air

FIGURE 3-3

TEST EQUIPMENT
TEMPERATURE CONDITIONING EXPERIMENT



unrestricted external pump configuration used for coolant circulation during the forced cool-downs. Special tests determined that the engine system performance was not affected by these cooling system configuration changes.

Mass and composite HC, NO, and CO values from these tests are presented in Appendix 1. A mode-by-mode computer printout is available from these tests but, because of its volume, the data are not included in this report.

Composite Emissions Sensitivity to Power Train Initial Temperature State

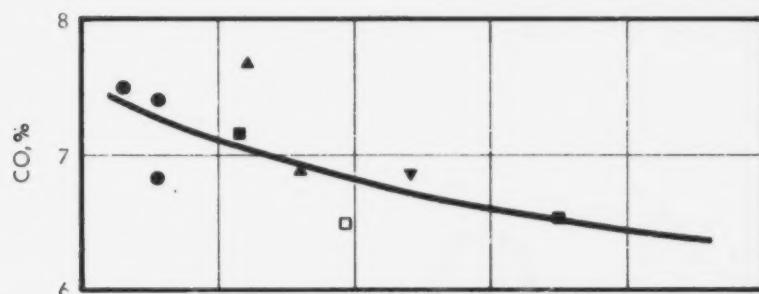
A main thrust of the study of temperature conditioning was to develop regression relationships between engine key temperatures and composite emission levels. If these relationships are sufficiently accurate, surveillance emission testing can be performed on vehicles with minimal temperature conditioning or in their "as-received" condition thereby eliminating time-consuming temperature conditioning. A thorough analysis therefore was conducted of the data recorded on the 11 cars tested. Examining many combinations of engine and ambient temperatures yielded the following results (Table 3-2):

- Block temperature generally proved to be the best indicator of emission level. Consequently, it was employed for the bulk of the regression analyses.
- CO emissions show the best overall correlation to temperature.
- No consistent correlation from power train to power train was found although vehicles with air reactor control systems were found to have stronger HC emissions sensitivity to block temperature than those controlled by engine modification.

Individual linear regressions were developed for each car in addition to a regression of the pooled data from all eleven cars. As shown in Table 3-3 and Figures 3-4 through 3-7, some regressions show no correlation of composite emissions to key temperature while others indicate a very strong relationship. For example, air reactor vehicles (Numbers 404 and 408) and vehicles within one manufacture (Numbers 401, 407, and 411) showed more pronounced HC emissions sensitivity to temperature than other generic types of power trains. This sensitivity is reflected by a relatively high

FIGURE 3-4
EMISSION SENSITIVITY TO
BLOCK TEMPERATURE

67 FORD 390 AIR



TEMPERATURE CONDITIONING

- FULL FEDERAL
- ▲ 1 HR WATER RECIRCULATION
- 0.5 HR WATER RECIRCULATION
- 3 HR FORCED AIR
- ▼ 2 HR FORCED AIR

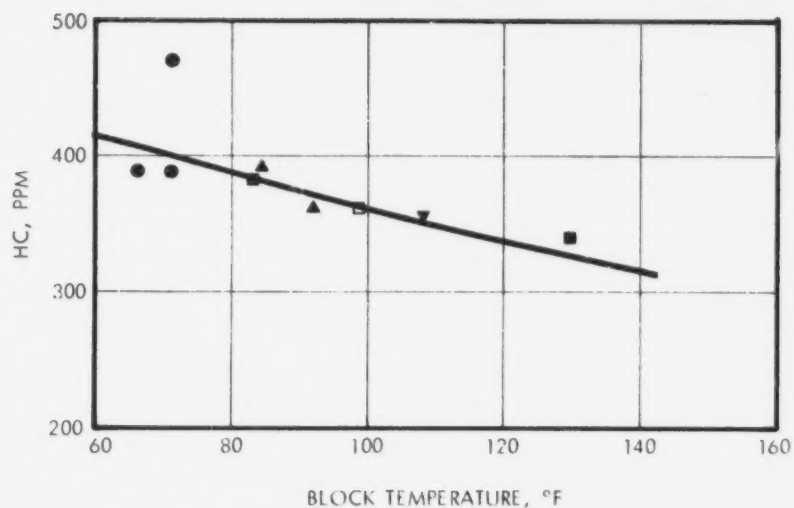


FIGURE 3-5

EMISSION SENSITIVITY TO BLOCK TEMPERATURE

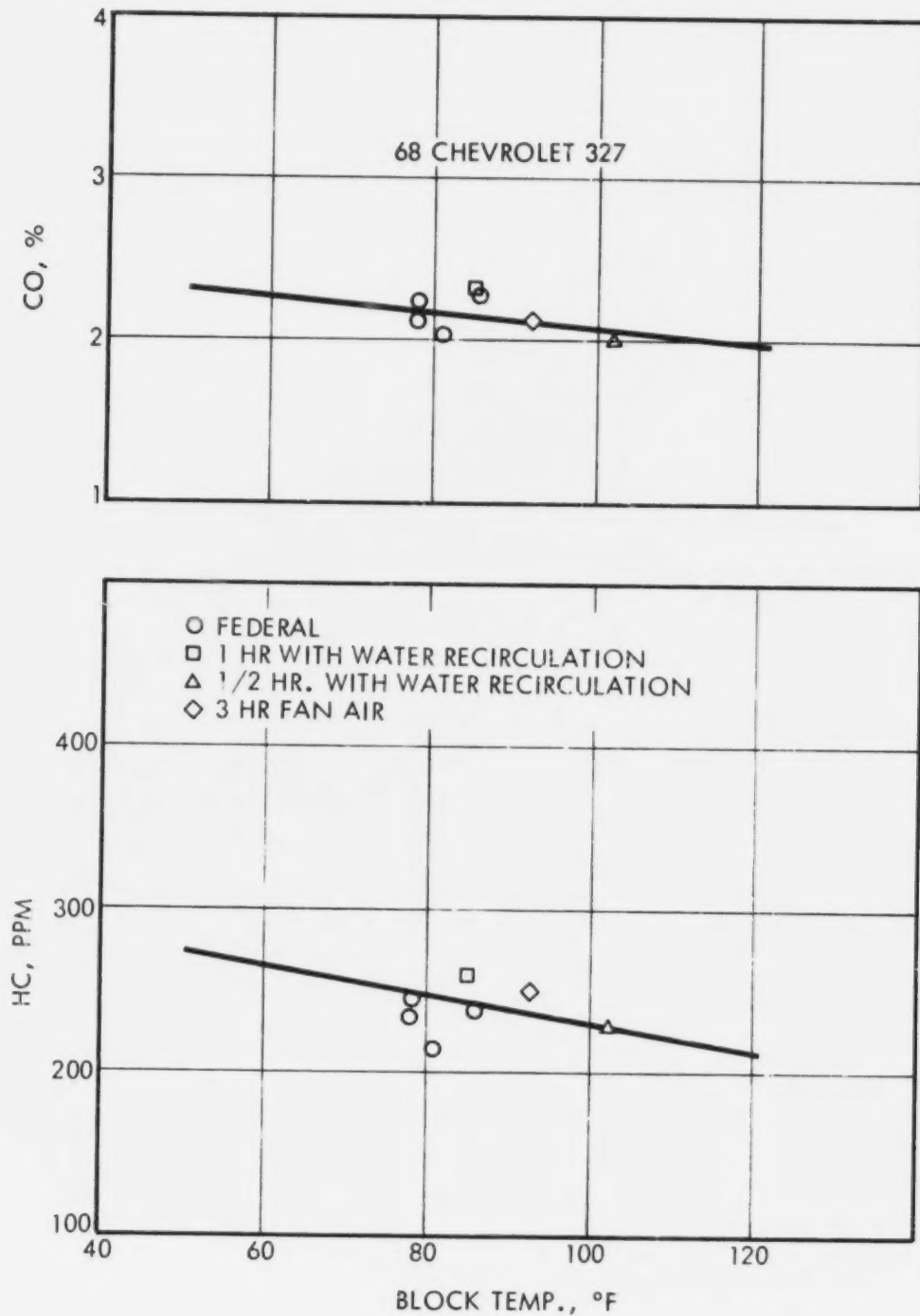


FIGURE 3-6
EMISSIONS SENSITIVITY TO BLOCK TEMPERATURE

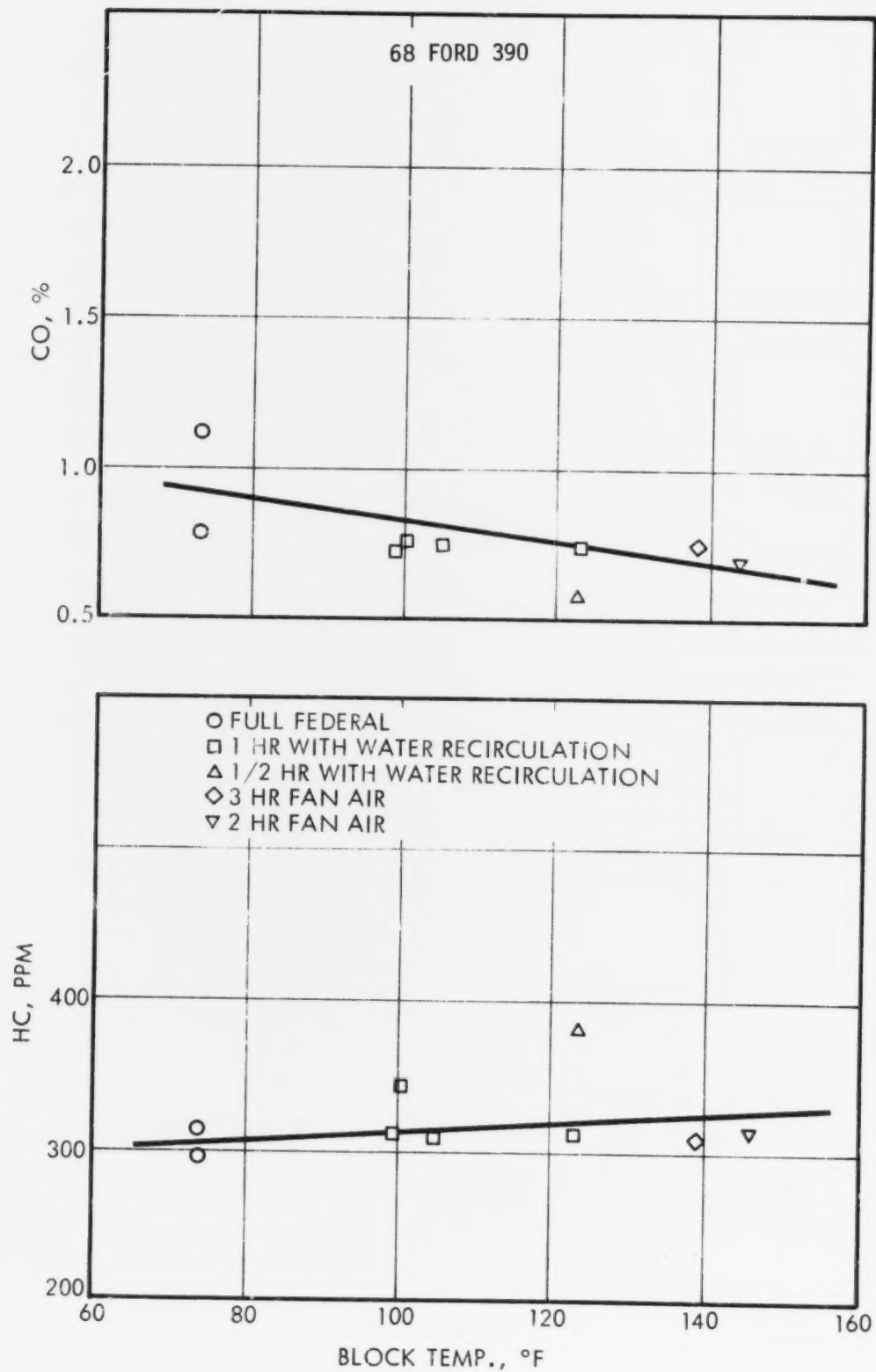


FIGURE 3-7

EMISSIONS SENSITIVITY TO BLOCK TEMPERATURE

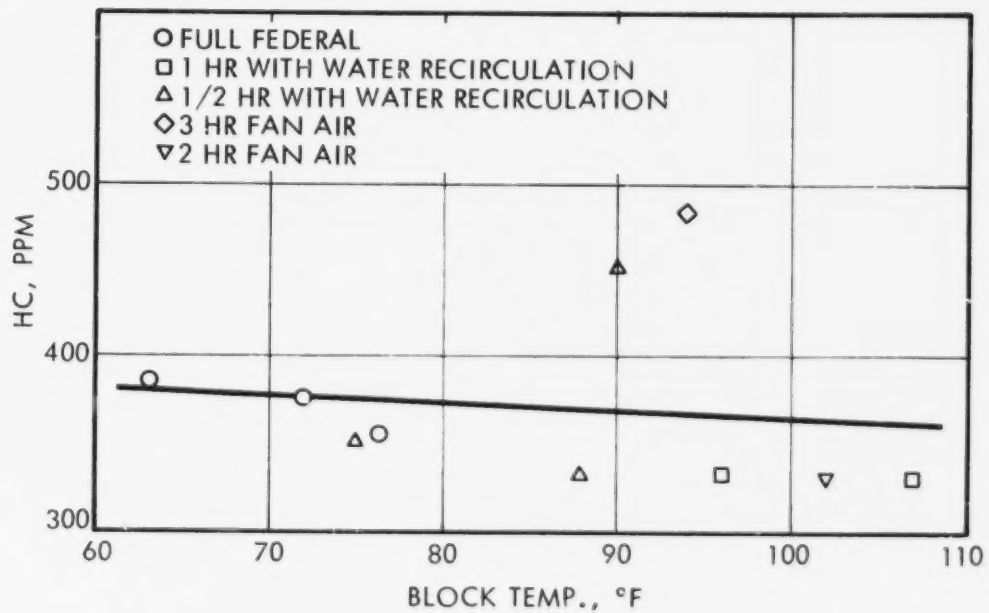
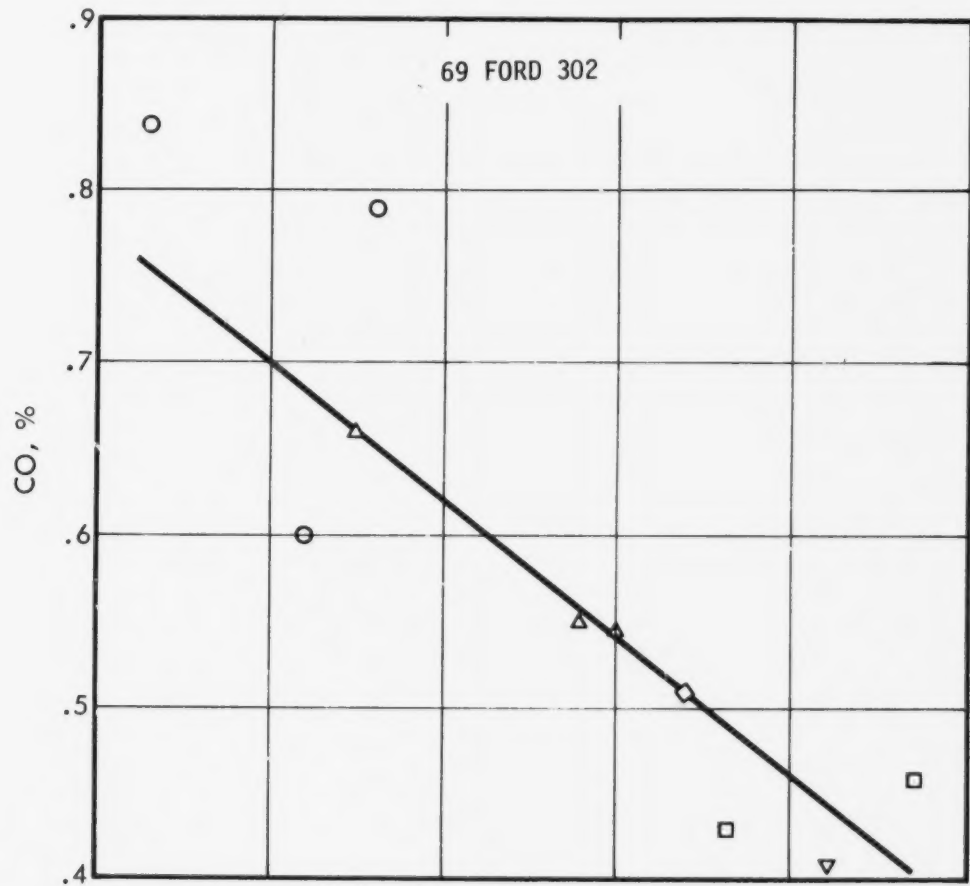


TABLE 3-2
EMISSIONS CORRELATIONS TO KEY
POWER TRAIN TEMPERATURES

Vehicle No.	Emission Correlated	Temperatures Correlated		Multiple Regression Coefficient
		Block	Carburetor	
401	HC	0		0.87
	HC	X	X	0.90
	CO	0		0.62
404	HC	0		0.70
	HC	Y	X	0.64
	CO	0		0.50
	CO	X	X	0.41
405	HC	X		0
	HC	Y	X	0
	CO	0		0.74
	CO	X	X	0.70
	CO		X	0.58
407	HC	0		0.69
	HC	X	X	0.68
	HC		X	0.66
	CO	0		0.84
	CO	X	X	0.83
408	HC		0	0.64
	HC	X	X	0.58
	HC	Y		0
	CO	0		0.45
	CO		X	0

0 = best correlated

TABLE 3-3

EMISSION SENSITIVITY TO TEMPERATURE CONDITIONING

$$\text{Emission} = A \times (\text{TEMP}) + B$$

Vehicle Test No.	Sample Size	HC COMPOSITE			Emission E	Regr. Coeff.	σ^*
		B	A	Temp X			
401	9	440.28	-1.228	104.2	312.3	.87178	16.500
402	7	316.28	-0.811	86.0	246.5	0	21.126
403	7	280.54	-0.181	87.1	264.7	0	12.146
404	9	514.37	-1.451	88.8	385.6	.70	28.335
405	10	400.63	-0.335	86.3	371.7	0	52.694
406	9	293.15	-0.226	109.0	317.8	0	26.100
407	8	462.28	-1.659	90.0	313.0	.6911	28.142
408	9	546.79	-0.953	82.2	468.4	0	29.475
409	8	270.77	0.038	100.4	274.6	0	15.399
410	7	311.08	-0.192	95.6	292.7	.2	9.445
411	11	257.06	-0.411	91.6	219.4	.4071	14.478

CO COMPOSITE							
401	9	1.73	-.0075	104.2	0.951	.6162	.212
402	7	2.63	-.0053	86.0	2.177	.11674	.108
403	7	2.72	-.0030	87.1	2.457	.32959	.100
404	9	8.22	-.0138	88.8	6.993	.49799	.415
405	10	1.26	-.0080	86.3	0.575	.73673	.100
406	9	1.13	-.0032	109.0	0.778	.52557	.117
407	8	3.15	-.0128	90.0	1.999	.8483	.136
408	9	1.02	.0142	82.2	2.188	.4472	.212
409	8	0.049	.0097	100.4	1.019	0	.452
410	7	1.09	-.0036	95.6	0.749	.75254	.066
411	11	1.91	-.0076	91.6	1.218	.7921	.109

NO COMPOSITE							
401	9	2110.	1.39	104.2	2255.	0	88.
402	7	612.	0.94	86.0	695.	0	54.
403	7	1155.	-1.29	87.1	1043.	0	99.
404	9	119.	0.22	88.8	138.	0	36.
405	10	2360.	2.88	86.3	2609.	0	188.
406	9	1704.	0.30	109.0	1737.	0	185.
407	8	1002.	3.62	90.0	1328.	0	162.
408	9	1281.	-0.16	82.2	1268.	0.10	104.
409	8	1058.	3.64	100.4	1423.	0	116.
410	7	1364.	-1.52	95.6	1219.	0	132.
411	11	1733.	6.11	91.6	2293.	0.23	184.

* Standard Deviation

value of slope coefficient, A, or multiple regression coefficient, or both. Changes in HC of approximately 1 ppm/degree F were considered large based on the sample tested. One vehicle (number 405) had an extremely large standard error about HC emissions (53 ppm) which was not reflected in a correspondingly high variability about its CO emissions. Two vehicles (402 and 409) within the same generic class had CO emissions which were poorly correlated to temperature. However, for the remaining power trains, CO sensitivity to temperature was more pronounced and, in some cases, very strong.

In an attempt to improve the correlations nondimensionalized emissions for small and medium sized V-8 engines were pooled and regressed against temperature. Emissions were nondimensionalized by dividing the HC and CO measurements for each vehicle made at various initial power train temperature states by their respective full Federal test procedure emissions. Regression equations of the following form, therefore, were obtained:

$$100 \times \frac{e}{e_F} = A T_{blk} + B \quad (3-1)$$

The results shown below do not represent a significant improvement in correlation, again indicating that significant differences in emissions sensitivity to temperature exist across power trains.

Emissions Sensitivity of Pooled Power Train Data

	A	B	R
HC -	.1385	108.54	0.21443
CO -	.4388	128.16	0.54317

The coefficient A now has the units of average percent change in emissions per degree change in temperature.

Because of the lack of consistent correlations between power trains, it is felt that regression equations developed from pooled data will be highly inaccurate. Regressions for generic types of power trains as opposed to pooled regressions, therefore, will be incorporated in the temperature conditioning model to predict emissions variability when vehicles are corrected to similar temperature states.

Mass Emissions Sensitivity to Initial Power Train Temperature States

To determine the sensitivity of mass emissions to block temperature, constant volume (dilution) samples were taken over nine cycles of the Federal procedure in parallel with the composite emissions for those vehicles tested in the temperature conditioning experiment. These mass emissions (all cycles weighted equally) were then regressed against block temperature, Table 3-4 and Figures 3-8 through 3-11. Comparing Table 3-4 with Table 3-3, it is evident that for the most part, those vehicle emissions which had strong temperature correlations for the composite weighted values had similar correlations for their mass emissions. There were exceptions for each of the two emissions types. Vehicles 402, 404 and 405 showed sensitivity differences for the composite and mass HC emissions while cars 405 and 411 showed CO emission differences for the two measurement procedures. The mass emissions of vehicles were more strongly correlated to block temperature than were composite emissions. The sensitivity of CO mass emissions to block temperature was particularly high, Figures 3-8 through 3-11. CO mass emissions changes of 2 to 1 are seen to be quite common in going from initial block temperatures of 125 to 65°F. This indicates that more careful temperature control, even when starting at ambient conditions, is required to obtain repeatable and precise mass emissions surveillance data.

The within-car and between-car HC and CO mass emissions variability is also indicated to be higher than that of the equivalent composite emissions data based on concentration measurements. Comparisons of means and standard errors between vehicle mass and composite emissions and pooled within vehicle variance are shown in Table 3-5. These estimates were obtained from a data set of 44 Federal tests comprising the temperature conditioning experiments and the pre- and post-tune-up tests from the orthogonal experiments, Reference 5. The ratio of between- and within-vehicle emissions standard errors to the mean emission values was also developed. This ratio is an indication of the power to which either mean emissions to the atmosphere or differences in fleet emissions can be estimated.

Mass emissions for both HC and CO are seen to have greater within-vehicle test variability as reflected by $\sigma_p/\bar{\mu}$ than composite emissions.

TABLE 3-4

EMISSION SENSITIVITY TO TEMPERATURE
CONDITIONING MASS MEASUREMENT

$$\text{Emission} = A \times (\text{TEMP}) + B$$

Test No.	Mean Emission	HC MASS		Regression Coefficient	σ^*
		B	A		
401	4.78	7.91	-.030	.906	.234
402	4.91	6.87	-.023	.696	.132
403	4.40	5.86	-.017	.07	.609
404	8.46	9.488	-.011	0	1.548
405	4.46	8.213	-.044	.618	.497
406	5.06	2.45	+.026	.209	.748
407	7.74	16.08	-.093	.608	1.240
408	4.78	6.31	-.019	0	1.166
409	5.75	6.38	-.006	0	.277
410	4.43	4.11	+.003	0	.697
411	3.09	4.13	-.011	.101	.344

CO MASS					
401	37.7	103.0	-.633	.966	2.88
402	57.6	132.0	-.867	.364	9.32
403	72.7	135.0	-.72	.238	18.6
404	265.0	301.0	-.405	0	23.7
405	18.9	38.9	-.232	.342	4.16
406	28.5	63.6	-.348	.642	4.54
407	102.7	185.0	-.919	.834	7.04
408	52.7	69.8	-.204	0	8.42
409	35.6	78.8	-.43	.479	6.69
410	29.2	57.1	-.277	.795	2.64
411	34.2	80.5	-.486	.206	12.3

NO MASS					
401	8.0	6.92	.01	.161	.447
402	4.38	8.39	-.046	0	1.049
403	3.86	3.27	.007	.181	.205
404	1.32	1.38	-.001	0	.491
405	9.09	6.93	.025	.050	.883
406	6.97	8.44	-.015	.478	.258
407	5.11	2.57	.028	.115	.939
408	2.70	3.02	-.004	0	.522
409	6.43	6.07	.004	0	.430
410	4.35	1.50	.028	.396	.587
411	9.39	8.55	.009	0	.822

* Standard Deviation

FIGURE 3-8

EMISSION SENSITIVITY TO BLOCK TEMPERATURE
(Mass Emissions)
1968 Plymouth 318

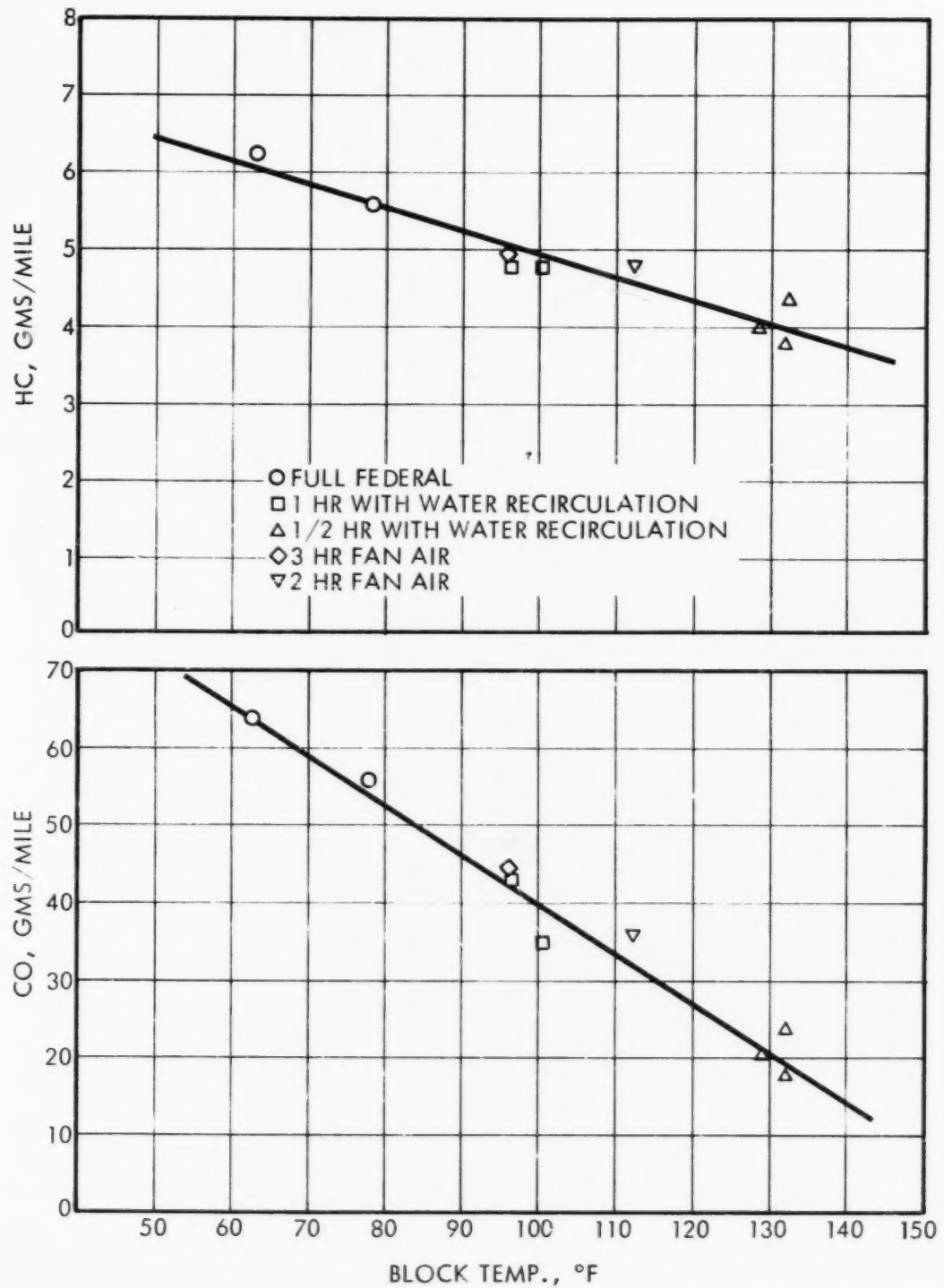


FIGURE 3-9

EMISSION SENSITIVITY TO BLOCK TEMPERATURE
1966 Chev 283

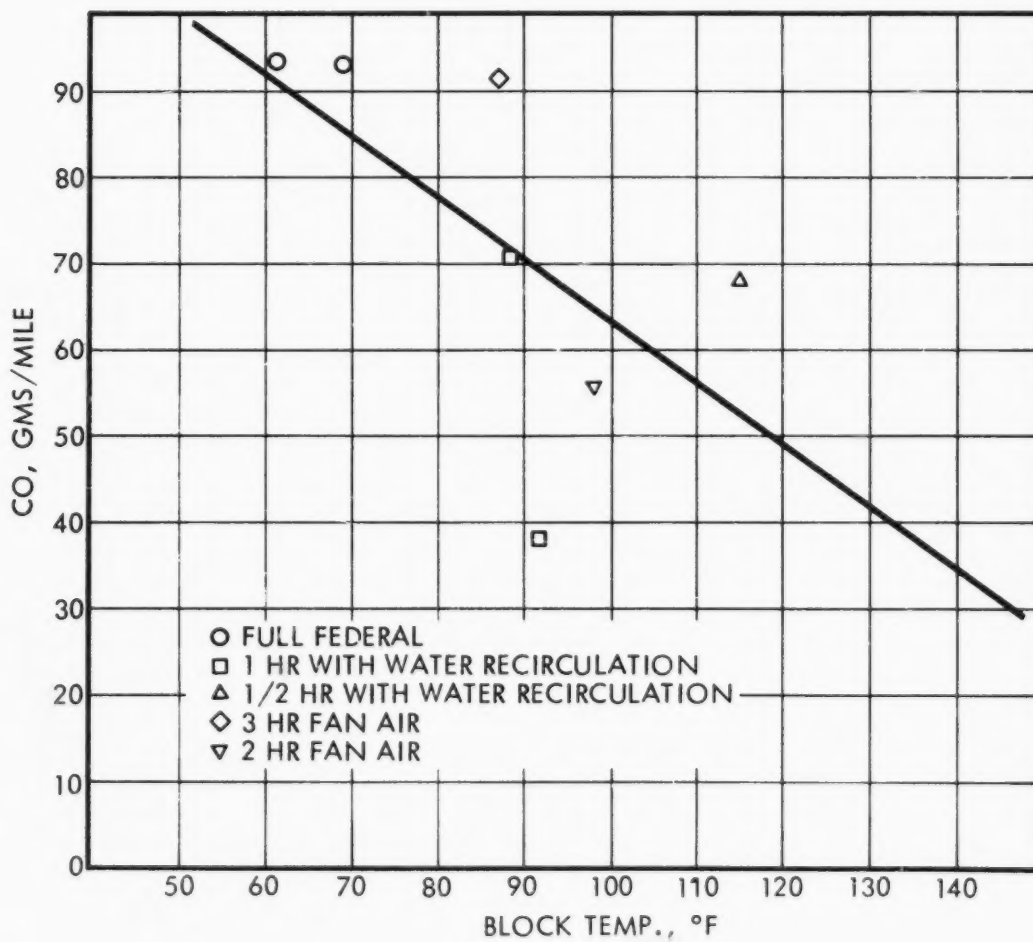
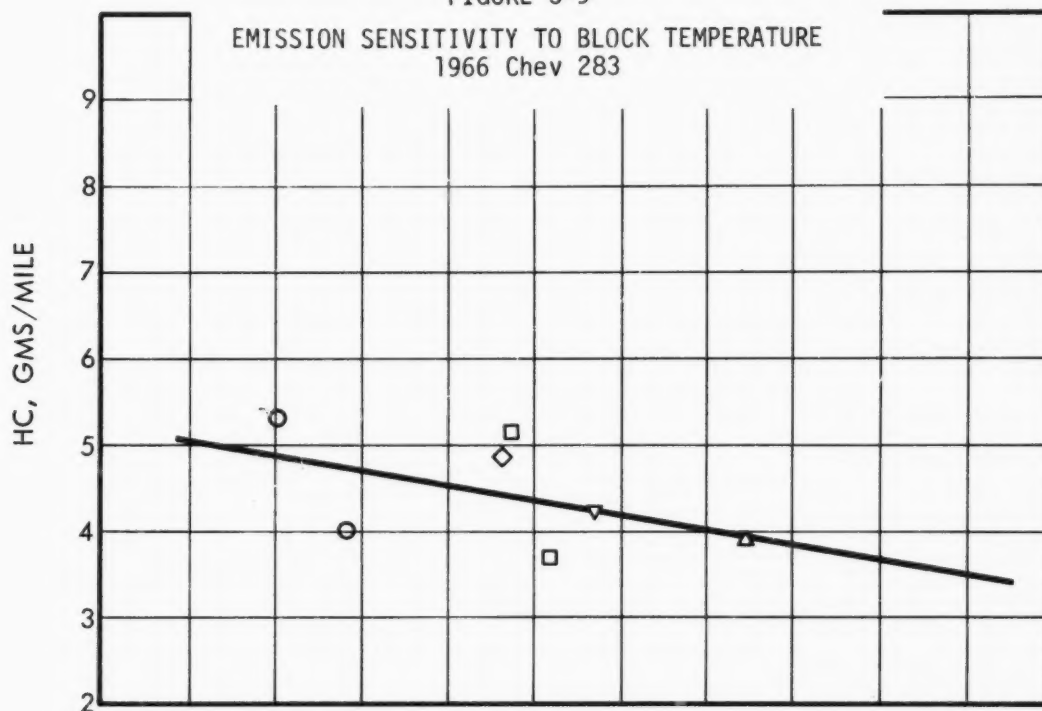


FIGURE 3-10

EMISSION SENSITIVITY TO BLOCK TEMPERATURE
1968 Ford 390

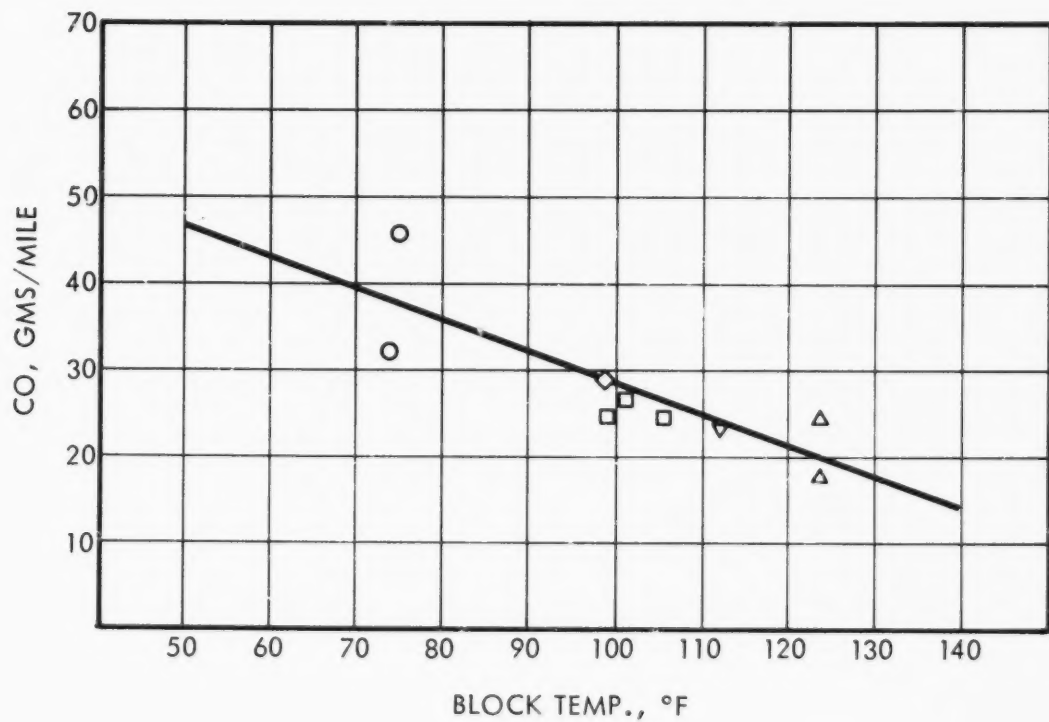
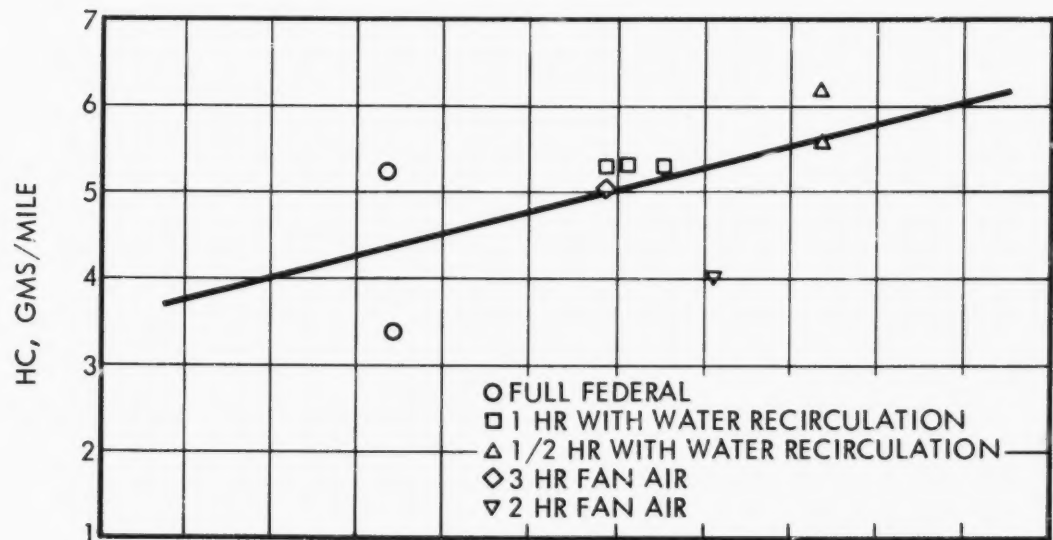


FIGURE 3-11

EMISSION SENSITIVITY TO BLOCK TEMPERATURE
1968 Buick 430

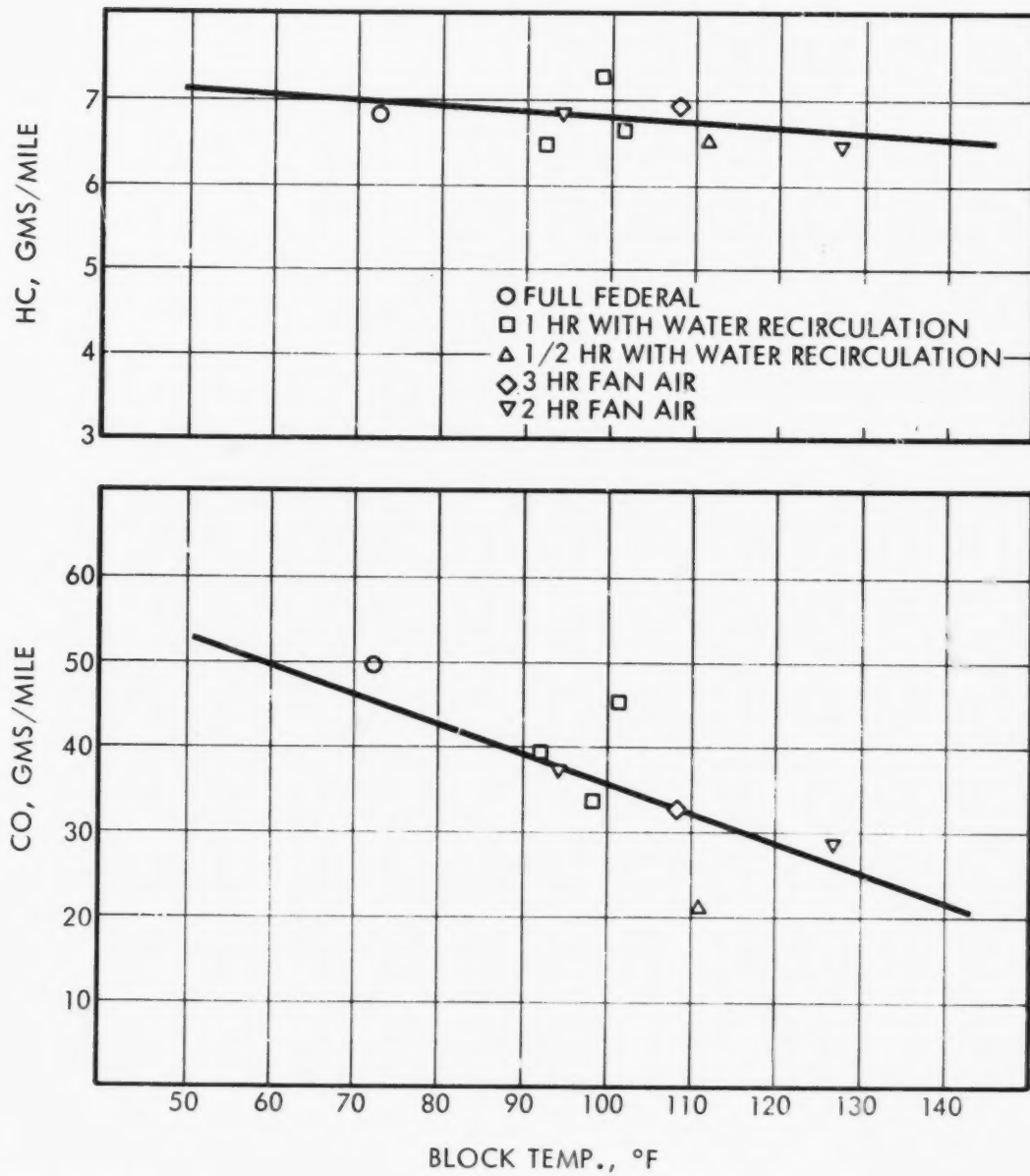


TABLE 3-5
COMPARISON OF ERROR COMPONENTS FOR MASS AND
COMPOSITE EMISSIONS TESTS
(44 TEMPERATURE CONDITIONING AND ORTHOGONAL TESTS)

EMISSIONS MEASUREMENTS	POPULATION MEAN EMISSIONS	STD ERROR ABOUT MEAN	POOLED WITHIN CAR STD. ERROR	$\frac{\sigma_m}{\bar{\mu}}$	$\frac{\sigma_p}{\bar{\mu}}$
	$\bar{\mu}$	σ_m	σ_p	dimensionless	
Mass CO, $\frac{\text{gms}}{\text{mi}}$	78.52	59.8	13.6	0.76	0.173
Com- posite CO, %	2.15	1.70	0.21	0.80	0.099
Mass NO, $\frac{\text{gms}}{\text{mi}}$	5.27	2.58	0.478	0.49	0.090
Com- posite NO, ppm	13 74	679	128	0.48	0.093
Mass HC, $\frac{\text{gms}}{\text{mi}}$	5.80	1.95	0.722	0.336	0.125
Com- posite HC, ppm	332	85	29	0.250	0.087

However, the car-to-car CO emissions variability as measured by mass or composite emissions is nearly identical, $\sigma_m/\bar{\mu}$ of 0.76 and 0.80, respectively, indicating that car-to-car mass emissions variability is less pronounced for CO.

Both within- and between-vehicle NO emissions variability as reflected by $\sigma/\bar{\mu}$ are approximately equivalent for both emissions test procedures. A larger difference in within as well as between-vehicle variability exists between the mass and composite emission measurements for HC than for the other two pollutants. The between-vehicle variability ($\sigma_m/\bar{\mu}$) however is significantly lower for both the mass and composite HC measurements than for either CO or NO emissions measurements. NO emissions have between-vehicle variabilities intermediate to HC and CO but closer to the variability of the HC data. CO emission measurements have by far the greatest between-vehicle as well as total variability and generally would set the surveillance program vehicle sample size for either mass or composite emissions tests. Because the variability of mass and composite emission measurements are similar for each pollutant of interest a surveillance program designed for one of the emissions measurement procedures would not have to be substantially modified if the other emission measurement procedures were subsequently adopted.

Correlation of Mass to Composite Emissions

The relationship between mass and composite emissions as determined by linear regression analyses for each of the three emissions is given below:

$$\text{CO } \left(\frac{\text{gms}}{\text{mi}}\right) = 14.32 + 29.85 \text{ CO } (\%), R^2 = 0.715$$

$$\text{HC } \left(\frac{\text{gms}}{\text{mi}}\right) = 2.346 + 0.010 \text{ HC } (\text{ppm}), R^2 = 0.714$$

$$\text{NO } \left(\frac{\text{gms}}{\text{mi}}\right) = 0.958 + 0.003 \text{ NO } (\text{ppm}), R^2 = 0.673$$

Applying the equivalent 1970 standard composite emissions values for a 4000-pound vehicle of 180 ppm and 1% (Reference 3) would indicate equivalent 1970 mass emission standards of 4.15 gms/mi and 44.1 gms/mi for HC and CO, respectively. These values compare reasonably well with those estimated by Mick, et. al. (Reference 3) of 3.56 and 40.0 gms/mi. The mass

emissions data reported in this reference are consistently lower by approximately 10% than those measured in this program. This probably is attributable to differences in the vehicle composition of the test population and in vehicle maintenance states.

These regression equations, of course, describe the mass concentration emission data analyzed and thus are restricted to use for converting emissions measurements in the range of concentration and mass emissions found in these data. Clearly, the first equation becomes highly inaccurate as the CO mass emission approaches 14.32 grams per mile.

Temperature Response to Conditioning Procedures

The temperature response of power trains to the various temperature conditioning procedures is important in predicting the average time required to prepare a vehicle for an emissions test. A simplified, one-dimensional, heat transfer model was developed which showed that, to a first approximation, the temperature response may be approximated by an exponential decay curve when the temperature data are suitably nondimensionalized. The nondimensional temperature parameter is a ratio of instantaneous block temperature less ambient temperature to the initial value block temperature less the ambient temperature.

$$T \text{ (dimensionless)} = \frac{T_b - T_a}{T_{bo} - T_{ao}}$$

Temperature response curves for six typical power trains to accelerated temperature conditioning using water recirculation plus forced air cooling are shown in Figure 3-12. Similar response curves are shown in Figure 3-13 for three cars cooled by forced air circulation only. Actual test data points for a number of cars to both temperature conditioning treatments are shown on Figures 3-14 through 3-16. As can be seen, the temperature response differs widely among power trains for identical temperature conditioning procedures. These data indicate that conditioning power trains to a specified temperature state rather than for a prescribed time interval is required to assure good test control.

Less variability was found in the temperature responses between cars treated by forced air cooling only than for cars cooled by water recirculation plus forced air cooling. This is largely attributed to inherent

FIGURE 3-12
TEMPERATURE RESPONSE
ACCELERATED CONDITIONING WITH
WATER RECIRCULATION

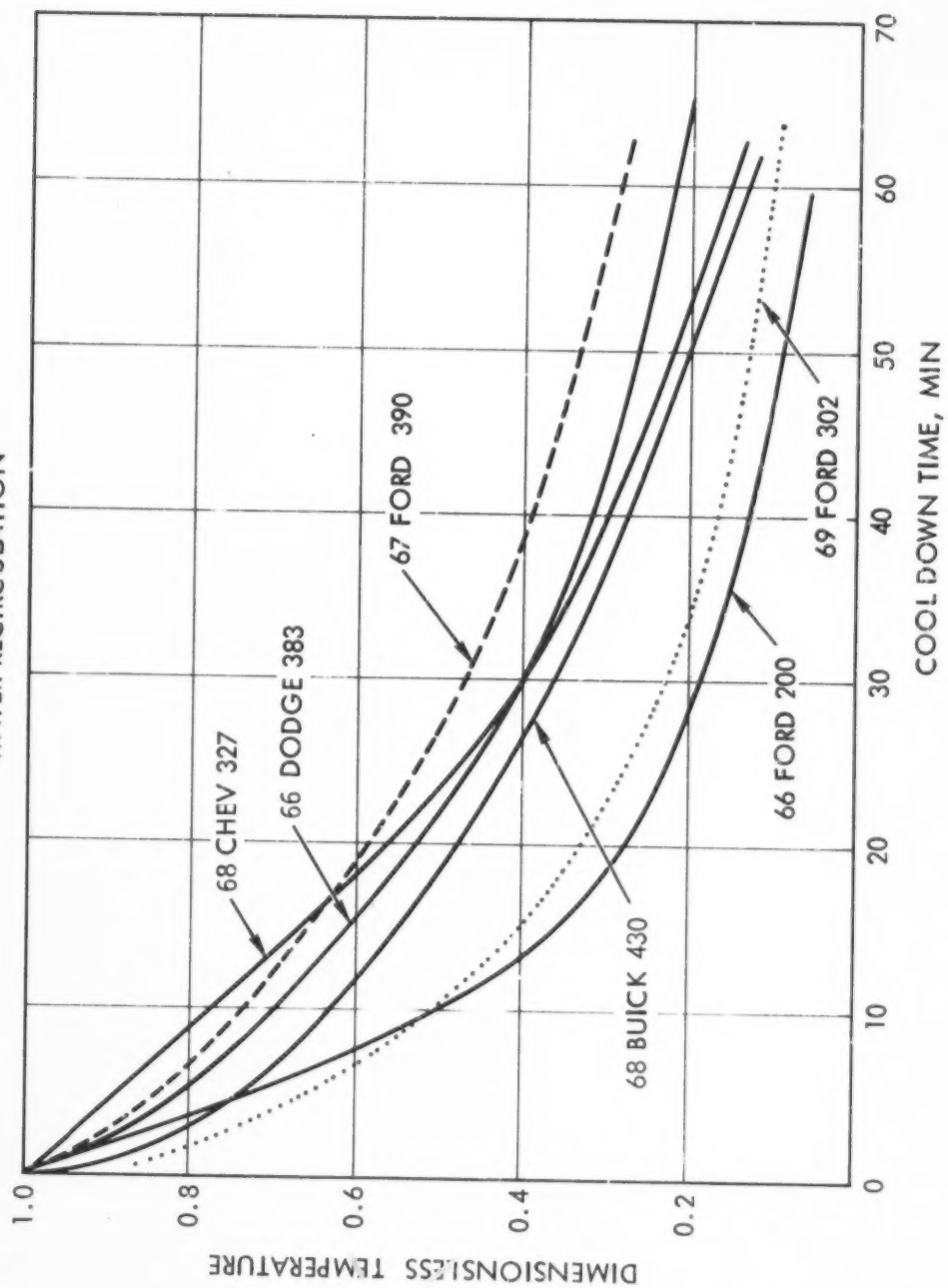


FIGURE 3-13

**TEMPERATURE RESPONSE
ACCELERATED CONDITIONING WITH
30mph FORCED AIR**

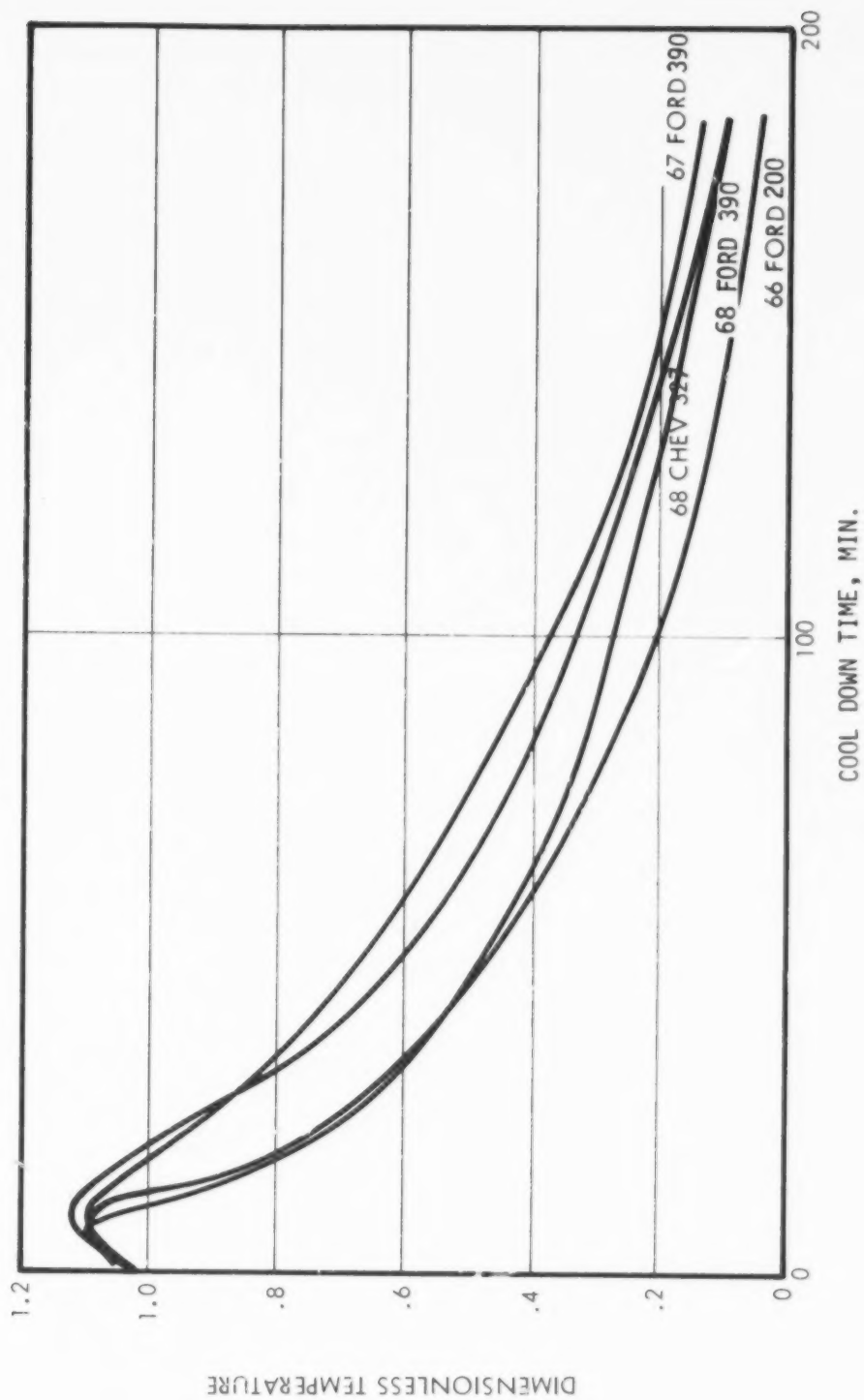


FIGURE 3-14

TEMPERATURE RESPONSE TO ACCELERATED COOL DOWN PROCEDURE

30 MPH AIR PLUS WATER RECIRCULATION
1969 FORD 302 CID

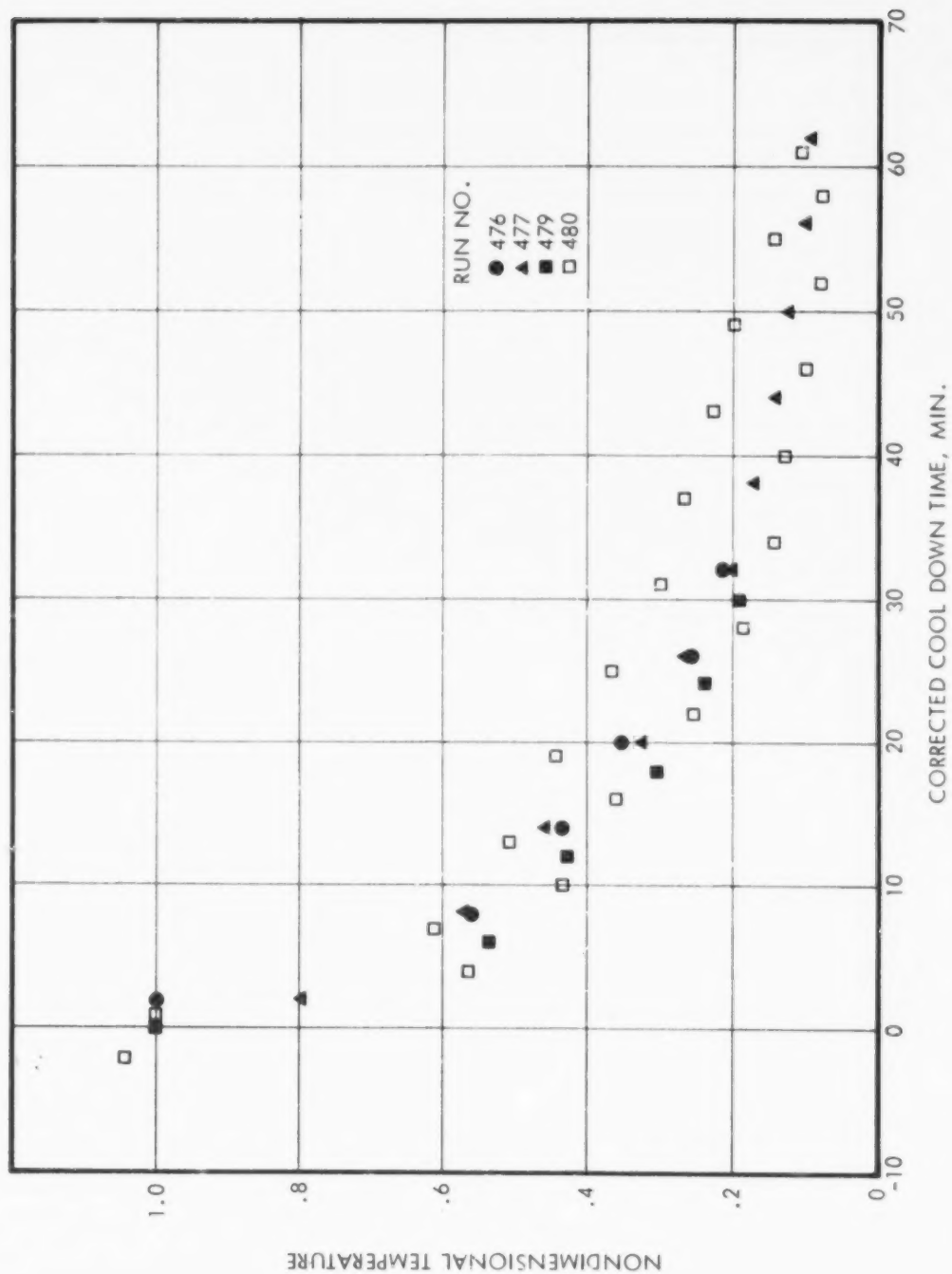


FIGURE 3-15

TEMPERATURE RESPONSE TO ACCELERATED CONDITIONING WITH
WATER RECIRCULATION AND FORCED AIR
1968 BUICK, 430 CID

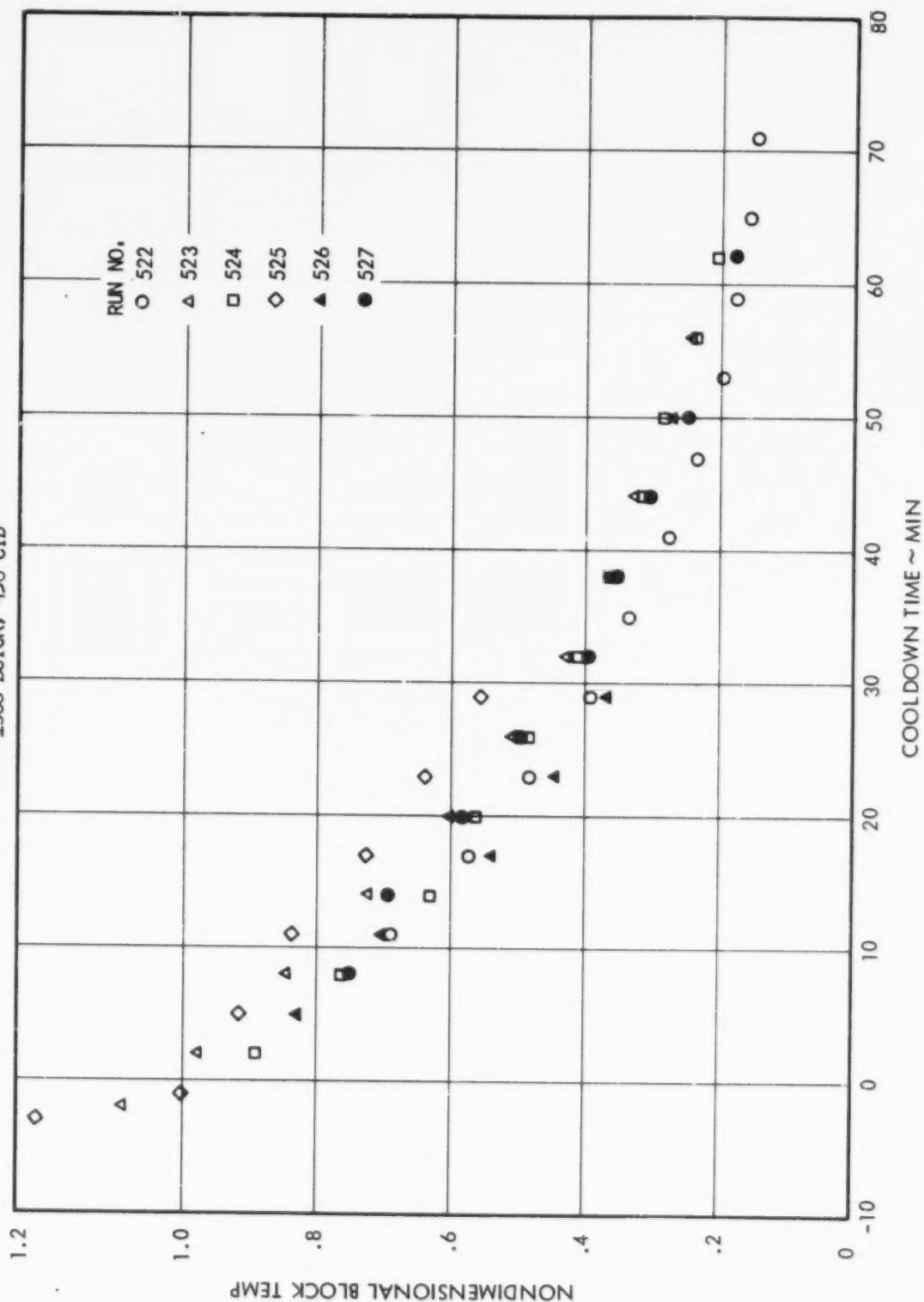
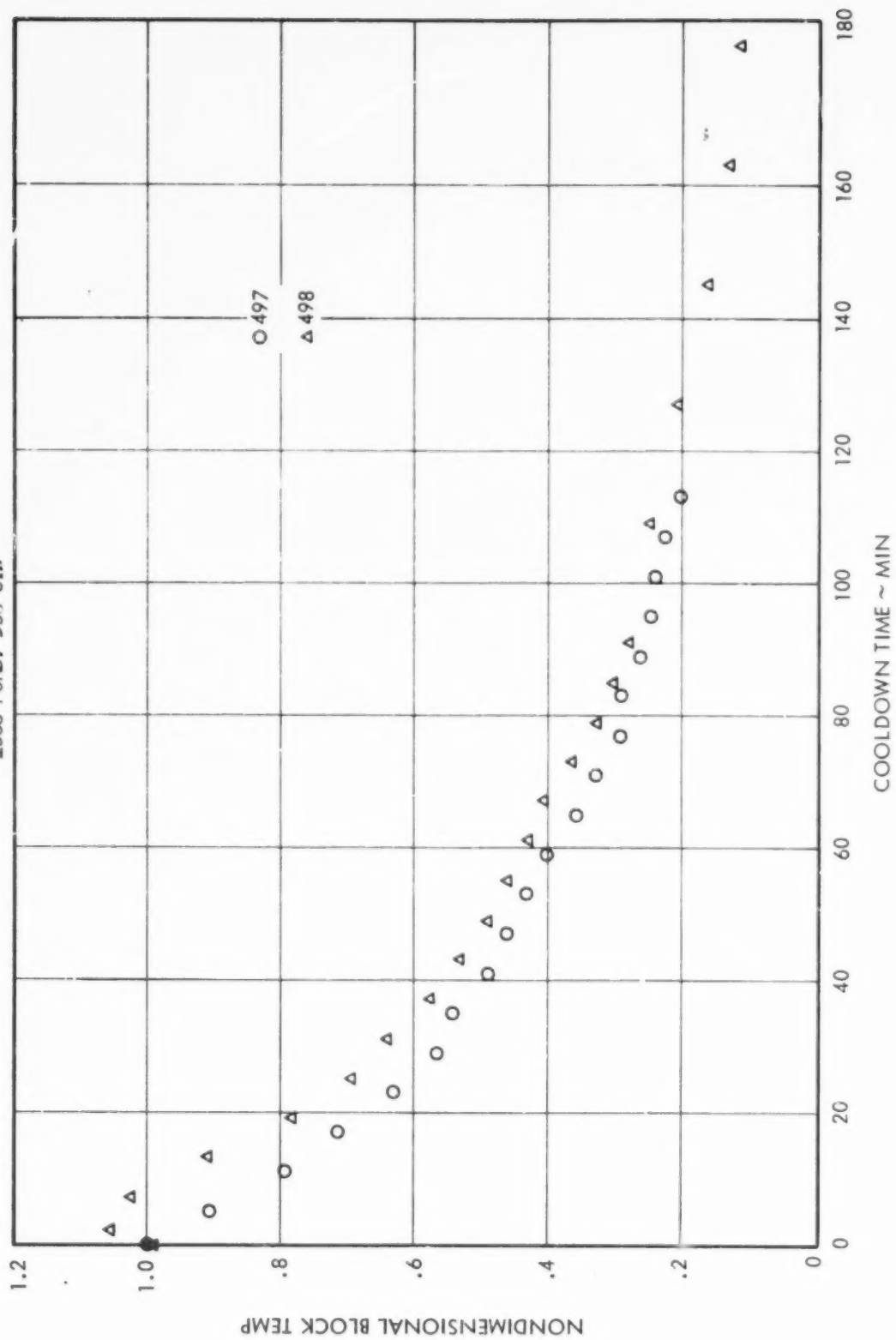


FIGURE 3-16

TEMPERATURE RESPONSE TO ACCELERATED CONDITIONING WITH
FORCED AIR ONLY
1968 FORD, 390 CID



differences in the cooling capabilities of the radiator system rather than procedure error. The response curves demonstrate that approximately 80% of the thermal energy in the engine block can be removed in 60 and 120 minutes for forced air cooling with and without water recirculation, respectively.

Data from the above figures may be used to predict the approximate time required to condition a vehicle to a specified temperature state when its initial state is known. The temperature state of the vehicle at the time it arrives for test will be a function of average speed and time required to drive the vehicle to the test station. For vehicles which are driven at the average speed of the test cycle for 3 minutes or longer, the block outlet water temperature can be assumed to have reached steady-state. For vehicles driven at lower speeds or for less time, predictions must be made of the engine temperature state. The initial temperature state data and the temperature response curves may then be combined to develop a mathematical model for estimating the total temperature conditioning time as a function of the average mileage driven to the surveillance station. This model in conjunction with the data of the regression analysis relating vehicle emissions to initial engine block temperature state will be used in the surveillance model to perform trade-offs to define an optimum procedure.

Population Characteristics

Because of the small sample size of the temperature conditioning data, a statistical evaluation was made to establish the degree to which this sample matches a larger population. EPA data were used as a reference data base. The results of HC and CO emission means, variances, and relative frequency distributions for the two data sets are summarized in Figures 3-17 and 3-18. The disparity in mean levels may be caused largely by the fact that EPA cars were less than a year old at the time of testing while the temperature conditioning test cars were up to 4 years old. This is reflected in the mean vehicle mileage for each test population (EPA: <10,000 mi/car; TRW: >30,000 mi/car). The shape of the distribution curves and the variances, however, are reasonably similar, except for the effect of CO emissions from Vehicle 404. The emissions of this vehicle were

FIGURE 3-17
RELATIVE FREQUENCY DISTRIBUTIONS OF CARBON MONOXIDE EMISSIONS
EPA AND TEMPERATURE CONDITIONING EXPERIMENT DATA

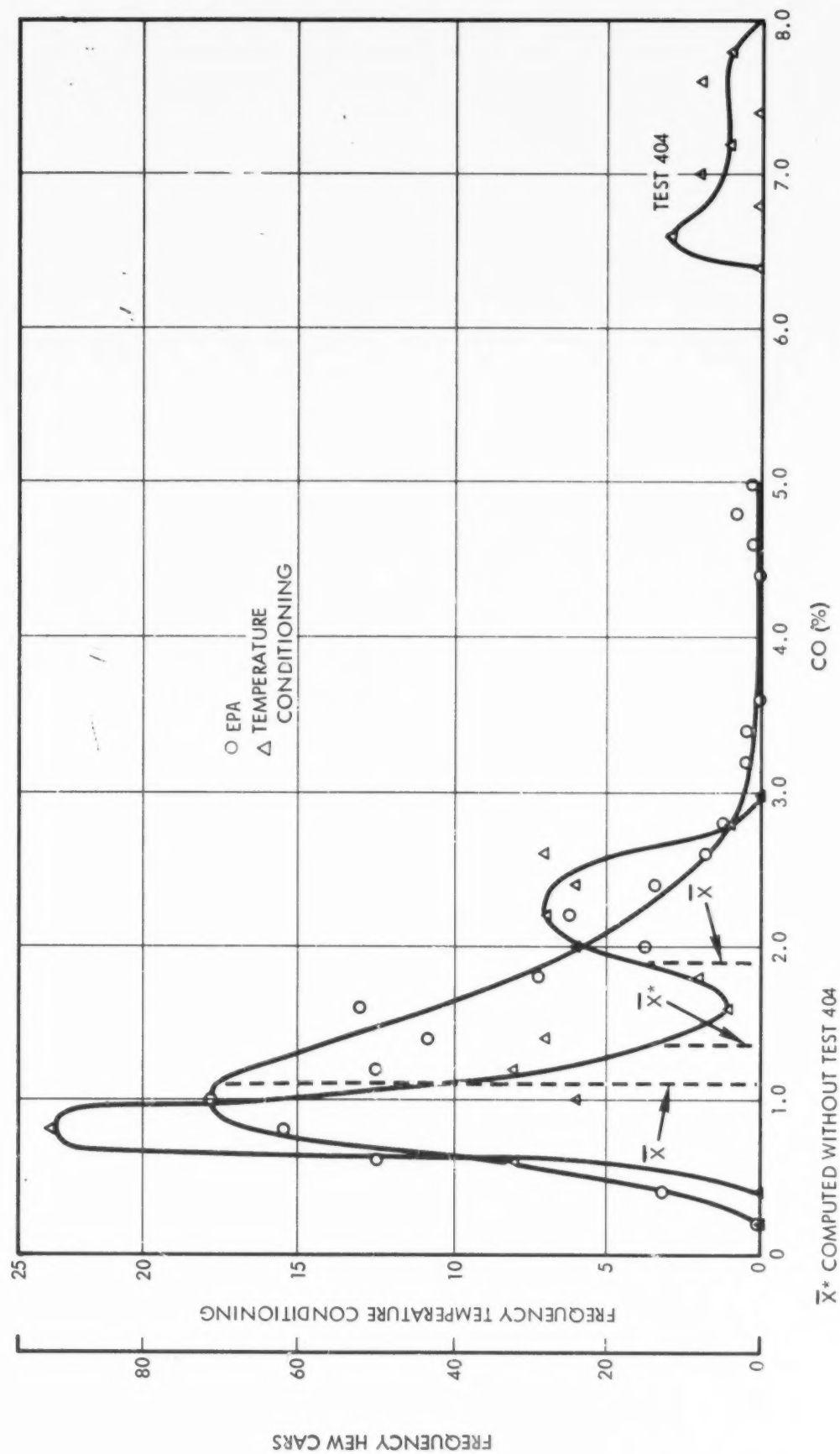
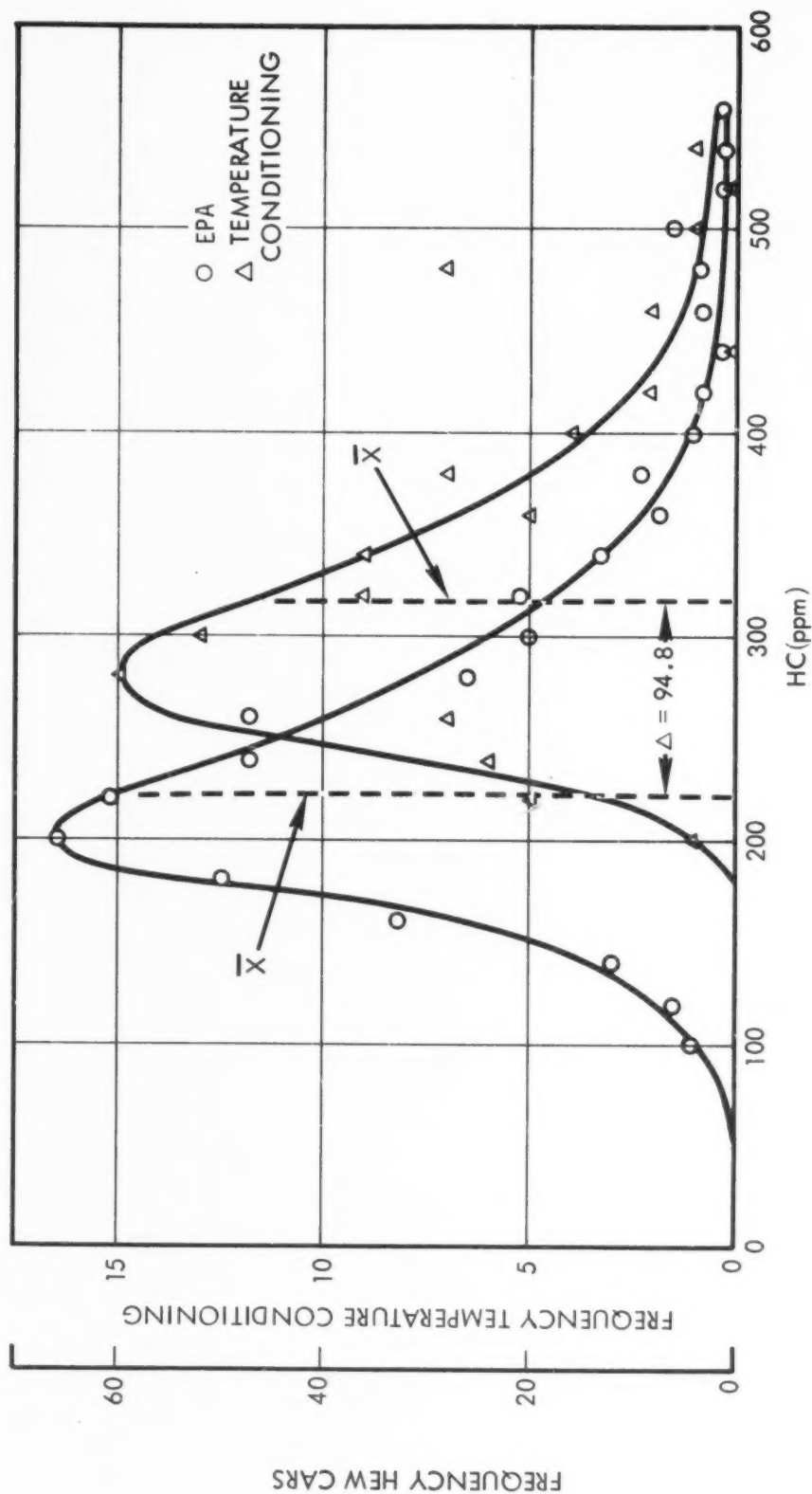


FIGURE 3-18

RELATIVE FREQUENCY DISTRIBUTIONS OF HYDROCARBON EMISSIONS EPA AND TEMPERATURE CONDITIONING EXPERIMENT DATA



sufficiently different from those of the rest of the temperature conditioning test population so that the vehicle was judged an outlier by statistical test and was discarded from the population. Vehicle 410 was introduced to replace Vehicle 404 and the tests were repeated with a similar power train. With this adjustment the sample of cars used in the temperature conditioning test were judged to be a part of the same population as the EPA vehicle sample.

3.1.2 Sample Selection

A statistical study was performed on emissions measurements from a representative data set to establish the effects of sample attributes and sample size upon the confidence with which emissions from a general population can be determined. For this purpose a large data set is required (preferably greater than 500 vehicles) which is internally consistent and describes vehicle emissions measured using the full Federal test procedure. The CRC and EPA provided two data sets for analysis which met these requirements:

- The 1968 EPA surveillance data obtained in Michigan and California
- Data from the General Motors idle parameter adjustment program.

The EPA data were used for this study because they constituted an internally consistent set nearly twice the size of the GM data set and because they could be used to assess regional and inter-laboratory differences.

Before the EPA Michigan and California data could be pooled to obtain the larger sample size desired, statistical tests were performed to determine if regional bias effects existed in the data. Biases could be caused by the effect of climate on the condition of the vehicle and instruments as well as by differences in calibration gases

The following approach was used to determine if regional or inter-facility effects existed in these data:

- The data were sorted by region and power trains were matched between the regions using the largest data sets possible
- Statistical tests were performed to determine if differences in mean emissions and their standard deviations existed between population data sets.

Regional populations were matched on the basis of vehicle power trains (engine displacement) as opposed to vehicle make and model because in this way significantly larger population sets could be assembled. With few exceptions however engine displacement is specific to manufacturer and relates strongly to vehicle weight. Regional statistical comparisons are summarized in Tables 3-6 and 3-7. Two data sets are used in the comparisons shown in Table 3-6. In the first set California and Michigan cars were matched one-for-one based upon identical engine displacements. In an effort to use more of the available California fleet data a second data set was constructed in which the cars again were matched by identical engine displacements but this time three California cars were matched against a single Michigan car. The relationship between Federal composite and hot cycle emissions was examined for each vehicle subset by computing both the ratio of average Federal composite to average hot cycle emissions as well as the difference between emissions means. Clearly, the ratio of HC emissions is extremely consistent across all four vehicle subsets. A systematic difference exists however between the sets of California and Michigan vehicles in terms of the ratio of CO emission means as well as both CO and HC differences in means. The tentative conclusion drawn is that relationships between hot and Federal test emission levels will probably have to be established uniquely for each surveillance region. This result is considered in Section 5.0 when comparing the cost-effectiveness of alternative temperature conditioning procedures.

Both normal and log normal distributions were assumed for the emission data and used to investigate regional differences. Comparisons based on assuming a log normal distribution are shown in Table 3-6 while contrasts based on a normal distribution are displayed on Table 3-7. The standard deviation based upon assuming normally distributed measurements is shown in Table 3-7 to differ significantly between the California and Michigan fleets. The standard deviation of the California data is larger than that of the Michigan data by nearly a factor of two. The California and Michigan test populations are shown by "F" and Welsh tests to be different at a high level of significance using both hot and Federal test measurements of HC and CO.

TABLE 3-6
SUMMARY OF REGIONAL STATISTICAL DATA

Statistic	Data Set #1		Data Set #2	
	Mich.	Calif.	Mich.	3X Calif.
Number of Vehicles	123	123	80	240
● <u>Emission Test Comparisons</u>				
HC Composite/HC hot	1.09	1.09	1.08	1.095
CO Composite/CO hot	1.49	1.21	1.47	1.22
HC Composite-HC hot, ppm	18	21	16	23
CO Composite-CO hot, %	0.35	0.25	0.34	0.27
● <u>Characteristics of Log Normalized Emission Data</u>				
σ , Log HC Composite	1.114 ⁺⁺	1.148 ⁺⁺	1.128 ⁰	1.145 ⁰
σ , Log CO Composite	0.223 ⁰	0.209 ⁰	0.243 ⁰	0.222 ⁰
Log HC Composite	2.316 ⁺⁺	2.361 ⁺⁺	2.326 ⁺⁺	2.390 ⁺⁺
Log CO Composite	-0.014 ⁺⁺⁺	0.114 ⁺⁺⁺	-0.035 ⁺⁺⁺	0.118 ⁺⁺⁺
● <u>Vehicle Attributes</u>				
Mileage				
- mean	5238	10014	5868	11161
- σ	6335	6508	7292	6831
Weight, pounds				
- mean	3584	3557	3692	3640
- σ	513	606	467	494

⁰ not statistically different

⁺⁺ significantly different at the 99% confidence level

⁺⁺⁺ significantly different at 99.9% confidence level

TABLE 3-7
COUPLED CONTRAST OF MICHIGAN VERSUS CALIFORNIA
AUTOMOBILE EMISSION LEVELS

Data Set	Parameter	MICH	CALIF	Variance Test	Welch Test	
				F	c	v
HC, Cold Fed. Test (7-cycle composite)	$\bar{X}$	213.6	245.4	4.38 ⁺⁺⁺	0.186	5.21 ⁺⁺
	s	53.7	112.4			
	n	123	123			
HC, Hot Fed. (6th & 7th cycles average)	$\bar{X}$	196.2	224.0	3.85 ⁺⁺⁺	0.206	2.64 ⁺⁺
	s	52.9	103.8			
	n	123	123			
CO, Cold Fed. test (7 cycle composite)	$\bar{X}$	1.079	1.456	2.28 ⁺⁺⁺	0.304	4.80 ⁺⁺
	s	0.479	0.724			
	n	123	123			
CO, Hot Fed. (6th & 7th cycle average)	$\bar{X}$	0.724	1.203	2.90 ⁺⁺⁺	0.256	5.47 ⁺⁺
	s	0.490	0.835			
	n	123	123			

Where:

++ = Test significant at 99% confidence level.

+++ = Test significant at 99.9% confidence level.

c = parameter related to sample variances in Welch test

v = parameter related to sample size and variances in Welch test

Log normalizing the data significantly reduced the variability of the CO data and moderately reduced HC variability. Statistical tests showed the variance of the HC data for California and Michigan car populations to be significantly different. The means of the log normalized data were also shown to be significantly different for the two basic car populations.

It is concluded that data should be log normalized when establishing statistical comparisons between populations. Data describing within-car variability on the other hand has been shown to be best approximated with a normal distribution. The statistical experiment described in the following section involves a population comparison and hence the data were log normalized. The determined emission means and variances then were transformed back to normal in order to combine them with other component errors by the root sum-squaring procedures.

It is important to note from Table 3-6 that California test cars on the average had accumulated 4200 more miles than the Michigan cars. Using both the California Air Resources Board (CARB) and AAA data, an estimate was made of the effect of accumulated mileage on emissions. A significant portion of the difference in mean emissions for the California and Michigan cars is explained when these data are corrected for the effect of accumulated mileage (Table 3-3). The following conclusions are drawn:

- Both the means and variances of normalized and log normalized emission data are significantly higher for California than for Michigan rental cars as is their average accumulated mileage.
- The normal standard deviations of emission levels are significantly higher for California vehicles, although the log normal standard deviations are similar across regions.
- The mean value and variance of vehicle weight is essentially the same for California and Michigan cars.
- A significant part of the emission level differences between Michigan and California rental cars is eliminated by accounting for mileage differences using correction factors based on AAA and CARB data.

Because not all of the differences in mean emissions were explained by mileage, the Scott Cross Reference Check data, Reference 6, were evaluated to determine if bias differences in instrumentation systems existed

TABLE 3-8
COMPARISON OF MICHIGAN AND CALIFORNIA REGIONAL EFFECTS

<u>Data Base</u>	HC Mean PPM	CO Mean %	Mileage	Weight Lbs
1968 EPA Surveillance Rental Cars				
Michigan	213.8	1.079	5238	3584
California	245.4	1.456	10014	3557
Difference (Calif.-Mich.)	31.4	0.377	4776	-27
1966 California AAA Fleet	Δ HC per 1000 Mi. at ~7000 Mi.	Δ CO 1000 Mi. at ~7000 Mi.	Δ HC For Mileage	Δ CO For Mileage
"Tune Up On Complaint"	10	.05	47	.23
1966 and 1967 Carb (Hot Cycle Data Adjusted to Full Federal Procedure)	6	.05	28	.23

between facilities. For this purpose linear regression analyses were made of the California vs. the Michigan Cross Reference Check emissions data, which yielded the following relationships:

$$\text{HC}|_{\text{Calif.}} = 0.975 \quad \text{HC}|_{\text{Mich.}} + 20 \quad \text{SEE} = 17 \text{ ppm} \quad (3-2)$$

$$\text{CO}|_{\text{Calif.}} = 0.995 \quad \text{CO}|_{\text{Mich.}} + 0.077 \quad \text{SEE} = .05\% \quad (3-3)$$

For these facilities to be free of bias the regression coefficient should be unity and the intercept equal to zero. The HC regression indicates a slight bias with the California instrumentation reading approximately 10-15 ppm greater than the Michigan equipment over the average instrument range utilized. No significant bias is indicated for the CO measurement.

When data developed above are used to remove both mileage and inter-facility bias effects, major differences in mean HC emissions between data sets are explained. Approximately 60% of the difference in mean CO emissions between data sets also is explained. However, because of the unexplained statistically significant differences in sample variances for both CO and HC and because the difference in CO mean emissions is only partially explained by mileage and inter-laboratory instrumentation bias effects, it must be concluded that the California and Michigan data sets are different and that one or both of the following hypotheses are true:

- There are regional differences caused by vehicle use,, maintenance, and origin
- Cubic inch displacement is not an adequate criterion for matching samples between populations.

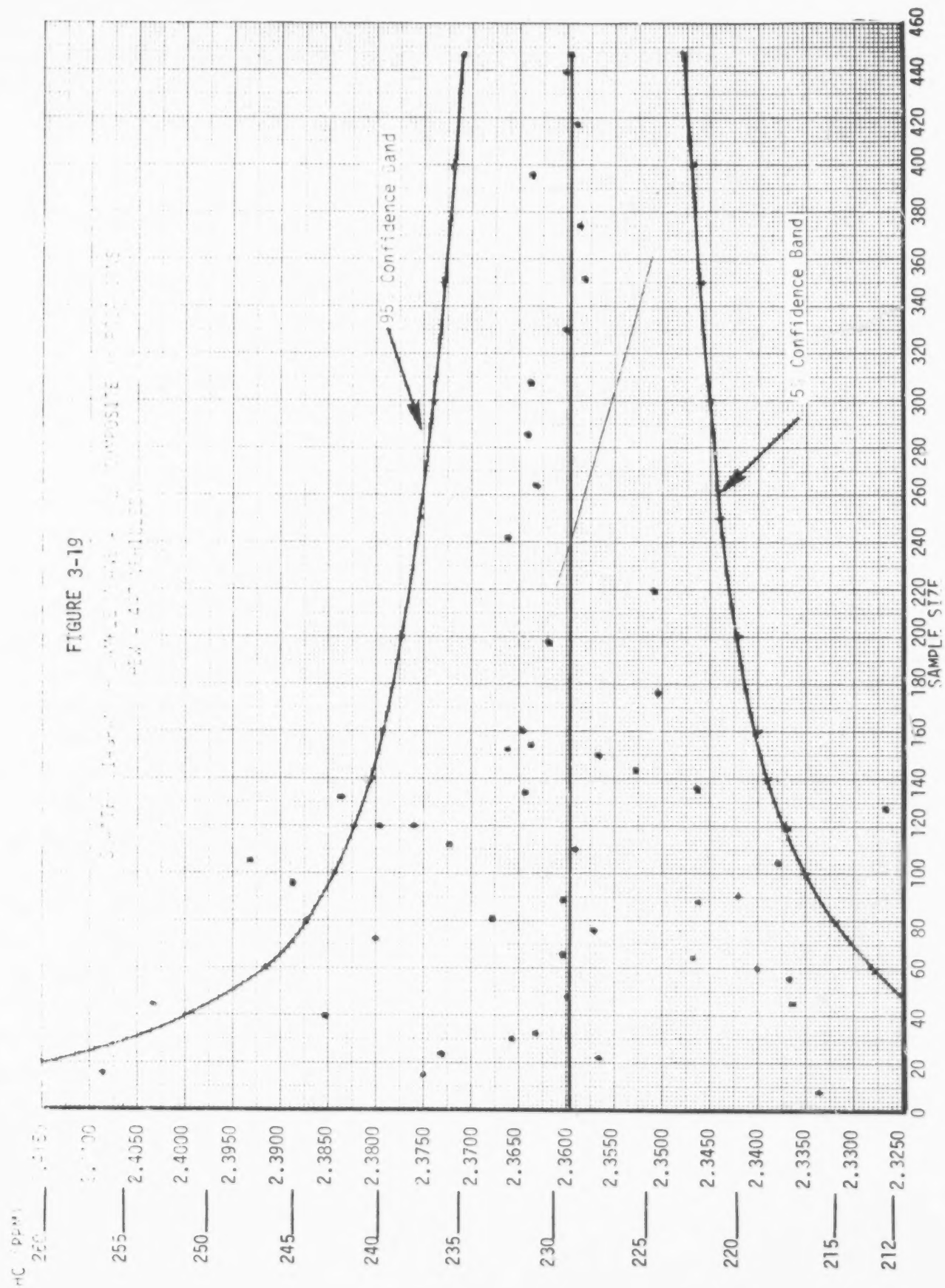
The EPA surveillance data next were used in a statistical experiment to establish a relationship between population sample size and measurement uncertainty at a given level of confidence. For this restricted purpose the California and Michigan data were combined to yield the largest possible data set. Combinations of these data sets should result in a population variance somewhat larger than that of either individual set and hence the estimates of sample size obtained from the following experiments should be somewhat conservative.

Samples of various sizes were randomly selected from the pooled EPA data (log emissions) and used to establish estimates of the population mean and variance. Results from these analyses for both HC and CO emissions measured by the full Federal as well as hot cycle procedures are shown in Figures 3-19 to 3-22. Log normalized emissions are plotted on the ordinate in order that a confidence band can be placed on the data. Overlaid on the results from the numerical experiment are estimates of one-sided confidence limits for both sample means and variances, using students "t" and chi squared distributions, respectively. Confidence levels of 5 and 95% were assumed. As can be seen, both the confidence band and the random data points indicate that the estimates of population mean and variance stabilize at between a 200 and 250 vehicle sample size. The conclusion to be drawn from these data is that when sampling is conducted on a generic vehicle classification, such as 1968 vehicles, the sample size need not be larger than that stated. These data are used in Section 4.0 for modeling the effect of sample size on population variance.

When more than one generic control system is to be sampled, the fleet size should be scaled accordingly. For example, in constructing the surveillance program for 1966 through 1970 vehicles, approximately three generic control types are involved. This would indicate a total sample requirement of between 600 and 750 vehicles. This same sample size is required regardless of whether full Federal or hot cycle procedures are used since the sample attributes stabilize at approximately the same sample size.

It should be noted that the variability displayed in the cited figures has both within car and between car components. Since component error sources are required for later modeling, the above data will require further treatment. It is proposed to use the data from the temperature conditioning experiments in which individual vehicles were repeatedly tested to make the within vehicle error correction. The pooled within vehicle errors (one sigma) for Federal composite HC and CO were estimated from these data to be 29 ppm and 0.21%, respectively, Table 3-3. This compares with a within vehicle plus between vehicle HC error of ± 95 ppm and 0.8% for HC and CO, respectively.

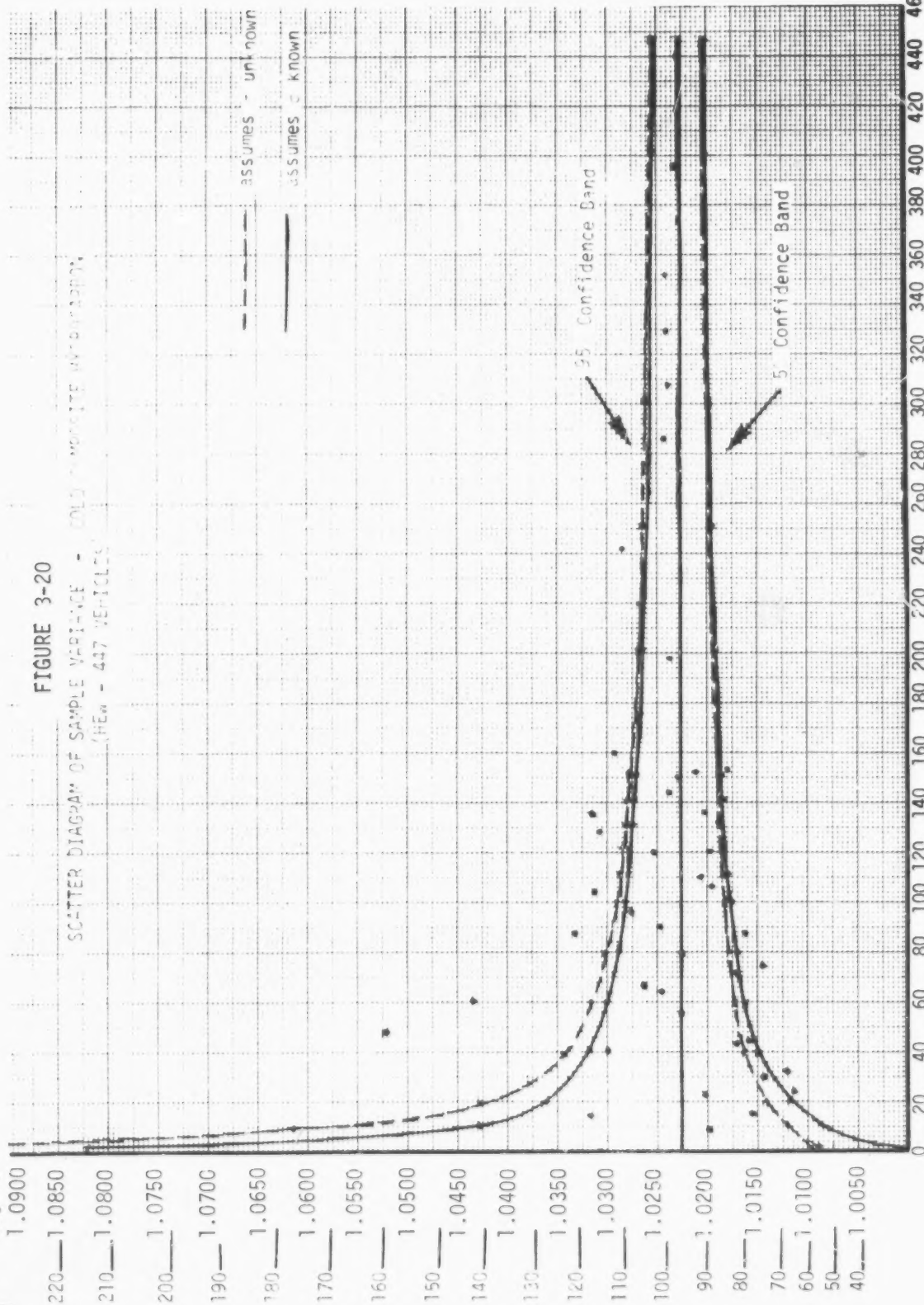
It is of interest to note that vehicle weight and cubic inch displacement, Figures 3-23 and 3-24, stabilize at significantly higher sample sizes than do emissions (approximately 300 vehicles).

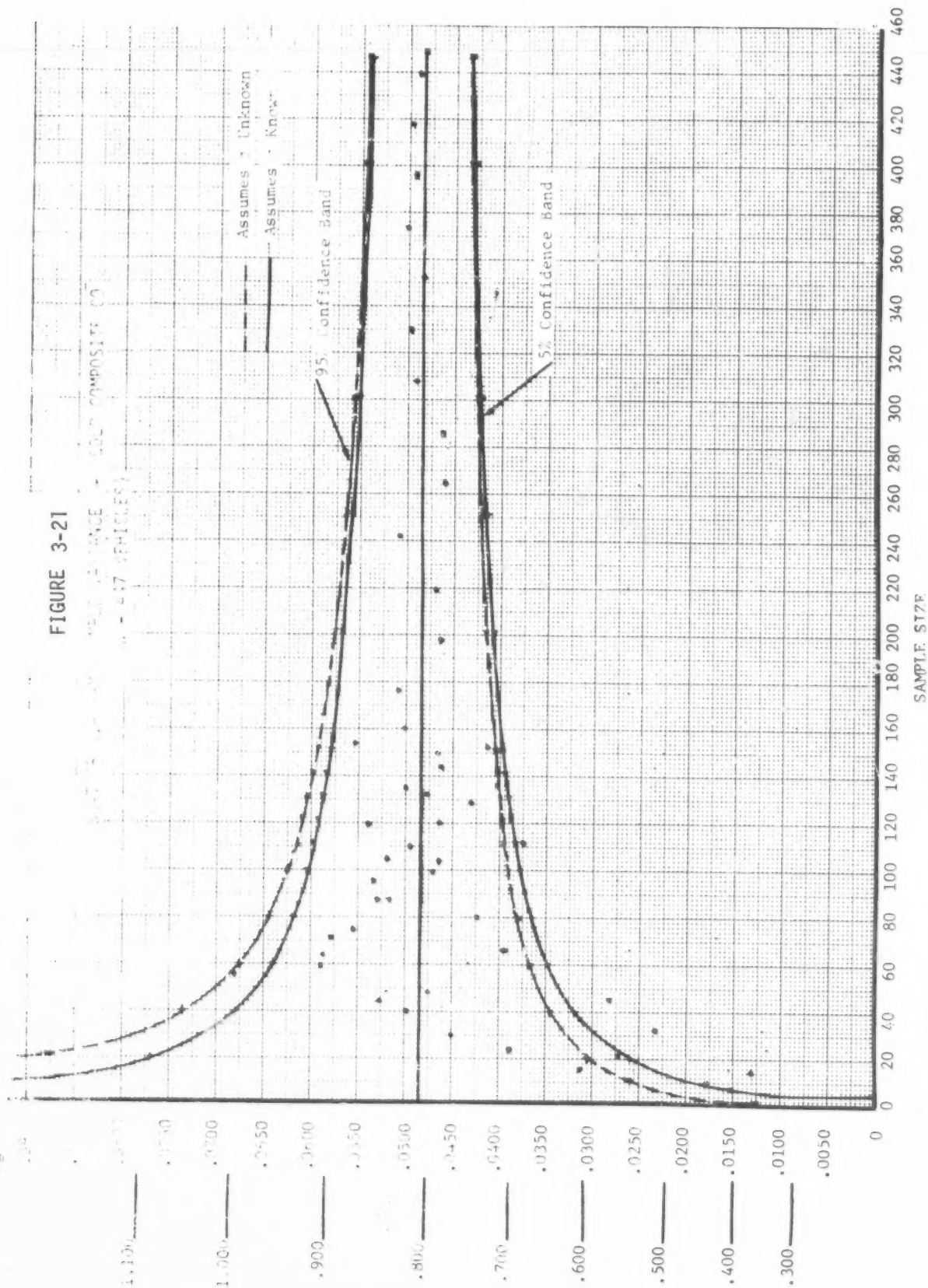


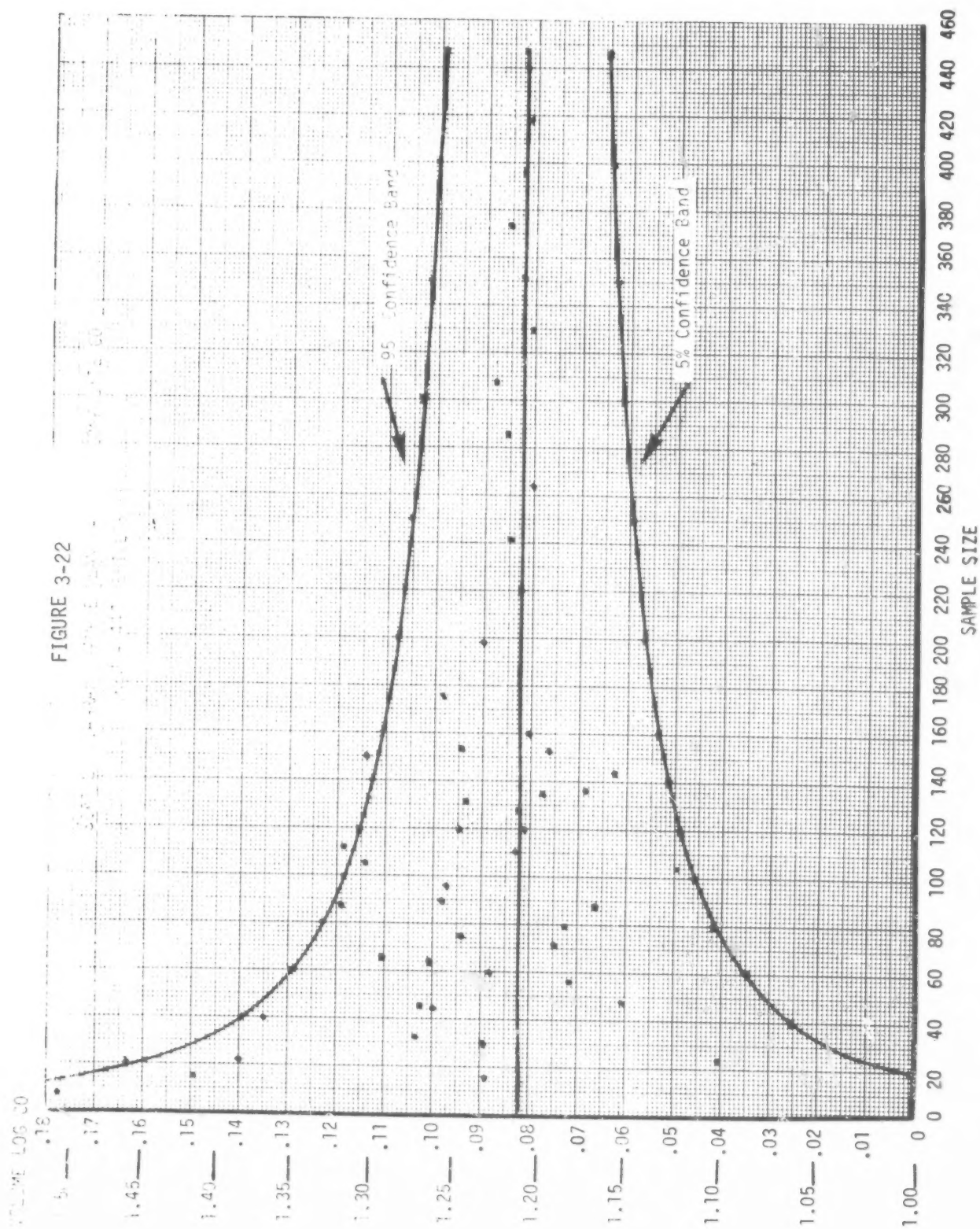
+1 Standard Variance of
Deviation
(pm)
Log HC

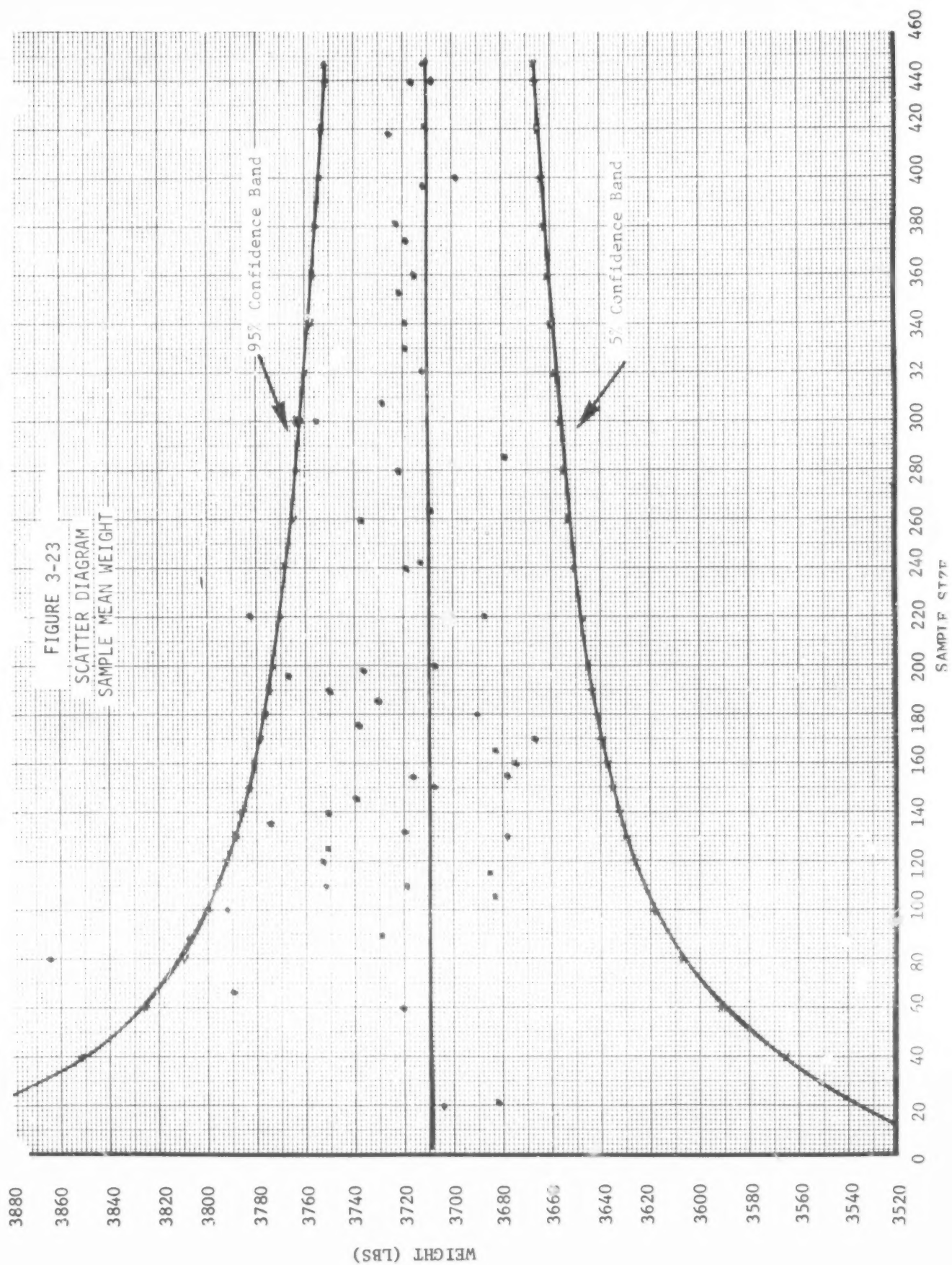
FIGURE 3-20

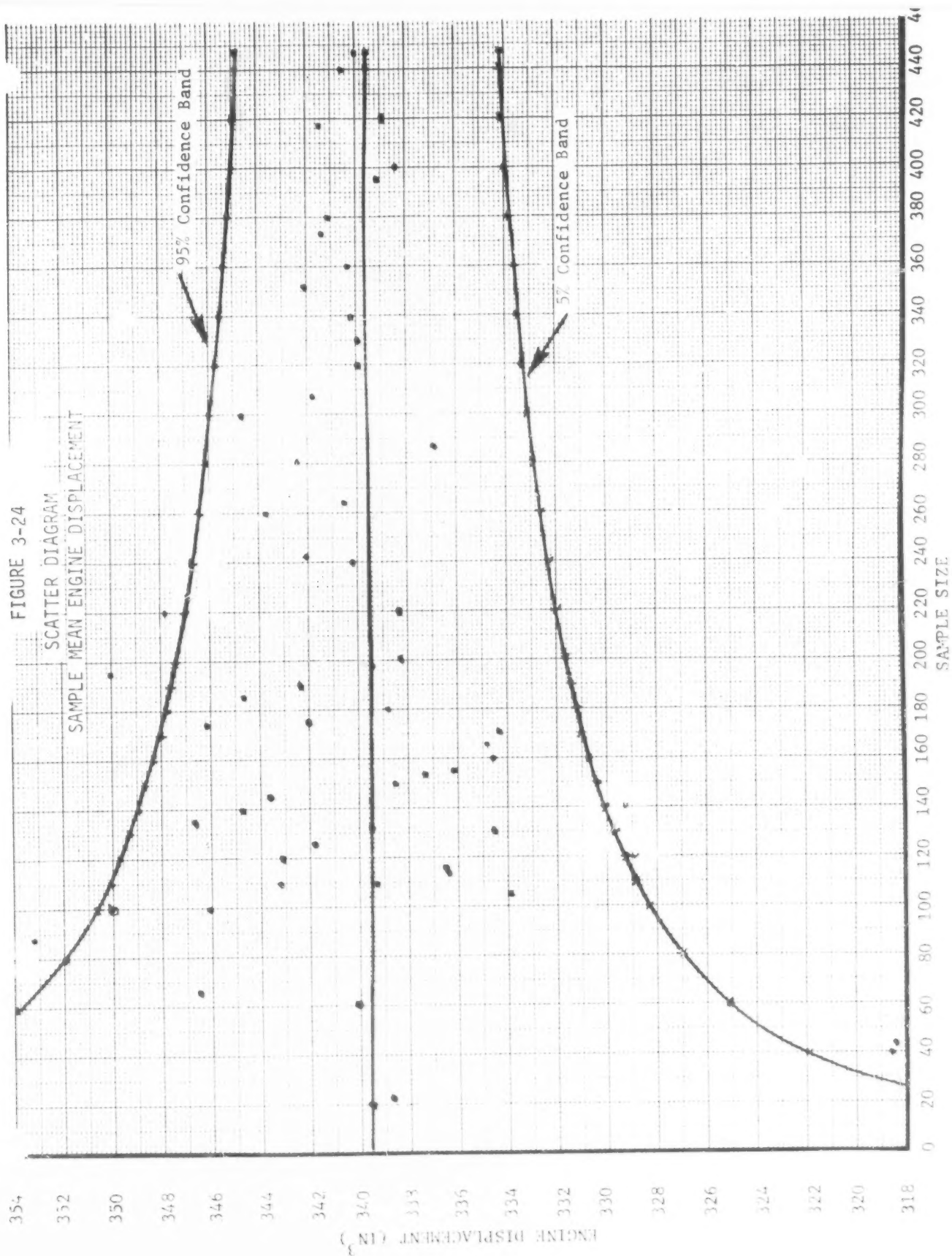
SCATTER DIAGRAM OF SAMPLE VARIANCE - OLD MONITORING DATA
(HEW - 447 VEHICLES)











3.1.3 Instrumentation Selection

A separate instrumentation evaluation program was performed to support the development of inspection/maintenance as well as surveillance procedures. These results are reported in detail in Reference 5. High quality, rapid response instruments suitable for performing a surveillance program generally employ nondispersive infrared sensors.

Typical instrument response to unknown input gas concentration levels are shown in Figures 2-7 through 2-11.

Average errors in the range of composite emission levels are 5 to 7 ppm and 0.02 to 0.04% for HC and CO, respectively. Values at the high end of these ranges were selected for use in this study to reflect conservatism since actual instruments would be used in an environment where other chemical compounds might interfere, thus causing larger standard errors.

3.2 Operational Considerations

Surveillance program costs are related to the cost of the direct or indirect labor required to perform the overall test procedures and to the equipment and facilities costs required to control the environment and perform the emissions measurement. Two types of studies were performed in order to quantize these costs:

- Operation time line studies to determine labor required to perform the various possible surveillance test procedures
- Facilities design studies to establish capital costs.

Ancillary cost data were accumulated from test equipment manufacturers as well as private contractors conducting Federal emission tests. These data primarily described the material costs and equipment maintenance costs directly associated with individual tests.

3.2.1 Operational Procedures

A number of institutions conducting vehicle surveillance or development activities using the Federal emissions test procedure were observed in operation. From these observations the task time line shown in Figure 3-25 was constructed. As indicated, two test technicians and a lead man are required during the test duration with very little dead time along the procedures time line. One technician serves as driver and operates the vehicle through the driving cycle while the instrument technician performs span checks at appropriate intervals and monitors the data recording and instrument operation. The lead man supports the test set-up and assures the test results. During the testing when driving cycles are being replicated, considerable lead man dead time results. This time may be shared with other related projects concurrently being performed in the facilities. The entire procedure from vehicle arrival to departure requires from 7 to 23 minutes for one and seven replicated driving cycles, respectively. It should be noted that these time estimates are for high production testing and must be extended to reflect test down-time caused by equipment maintenance and vehicle availability.

Times to setup the vehicle for temperature conditioning using the forced cooling water recirculation procedure reported in Section 3.0 were observed on the first six temperature conditioning test vehicles, Table 3-9. Activities reflected in these setup times were to:

- Drain radiator cooling water to level below top hose
- Remove cooling water thermostat and replace hose
- Refill radiator and turn on recirculating pump
- Attach thermocouple to block

TABLE 3-9
TOTAL AVERAGE LABOR TIME TO SETUP TEMPERATURE CONDITIONING PROCEDURE
(Forced Air Cooling with Water Recirculation)

Temperature Conditioning Test Vehicle Identifica- tion Number	401	402	403	404	405	406
Time (minutes)	10	10	20	16	15	10

SURVEILLANCE PROCESS FLOW CHART



The average time for the six vehicles is approximately 13 minutes.

The reverse procedure must be performed prior to the emissions test to restore the car to its "as-received" condition. The average time for this procedure was significantly shorter as the system had been previously opened and the engine block was cool. Seven minutes were allocated to restore the vehicle cooling system to its original state. The total procedure therefore was estimated to require an average of 20 minutes.

Setting up the cooling procedure in which only the cooling fan is used requires lifting the hood and installing a thermocouple on the block. The total time to setup the equipment for this procedure, as well as to restore the vehicle to its original configuration, was estimated to be 10 minutes.

The remaining significant direct labor costs are those associated with:

- Vehicle acquisition
- Equipment and facility maintenance

Estimates of these operating costs are presented in Section 4.0.

3.2.2 Facilities and Equipment Requirements

The equipment required to perform an emissions test is commercially available. Prices for these components are summarized in Section 4.0. Two capital cost items however are peculiar to the type and size of a surveillance program:

- The test and storage facilities required for various vehicle acquisition and temperature conditioning options
- The data management system.

Facilities Requirement

Preliminary layouts of work areas and equipment for several surveillance test facility options were made to provide a consistent base from which to compare different surveillance policies and procedures. These layouts are used to estimate facility requirements and hence surveillance program capital costs. Layouts for three basic options were prepared:

- Mobile stations conducting shortened emissions test procedures

- Fixed stations conducting shortened emissions test procedures
- Fixed stations conducting the full Federal test procedure.

Figure 3-26 shows the dimensions of a mobile station using an enclosed trailer which houses the basic emission measurement equipment. The dynamometer can be carried on the same trailer chassis or mounted permanently on a separate trailer. In addition to the customary equipment, portable electrical generators are included in the facility to be used either for service in remote areas or for short testing periods where power hook-up may not be economically justified.

Figure 3-27 presents a layout of a fixed surveillance station designed for use with a shortened emissions test procedure in a region of mild climate. The facility consists of a basic 17 x 23 ft (400 ft²) module and two test lanes. The module is composed of two sections, administrative and equipment storage. The sides of the equipment area adjacent to the test lanes are removed during operation and the equipment rolled out. Although dynamometers are shown in both lanes, one lane could also be used for accelerated temperature conditioning. The same general configuration for a totally enclosed facility which could be used in areas having more frequent rain or snow is shown in Figure 3-28. Total building floor area for the layout is 1050 ft².

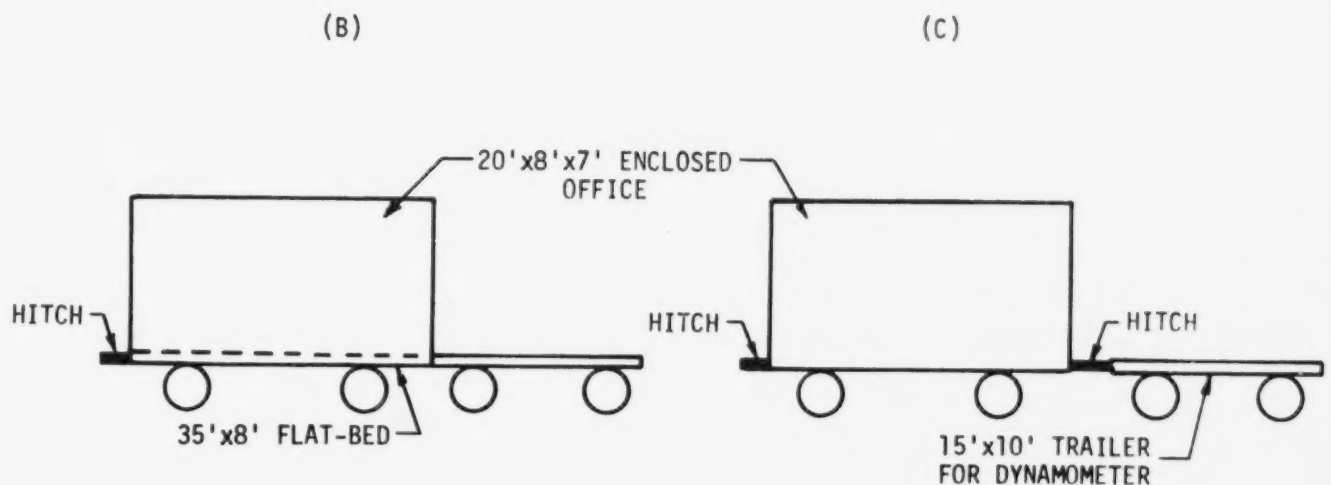
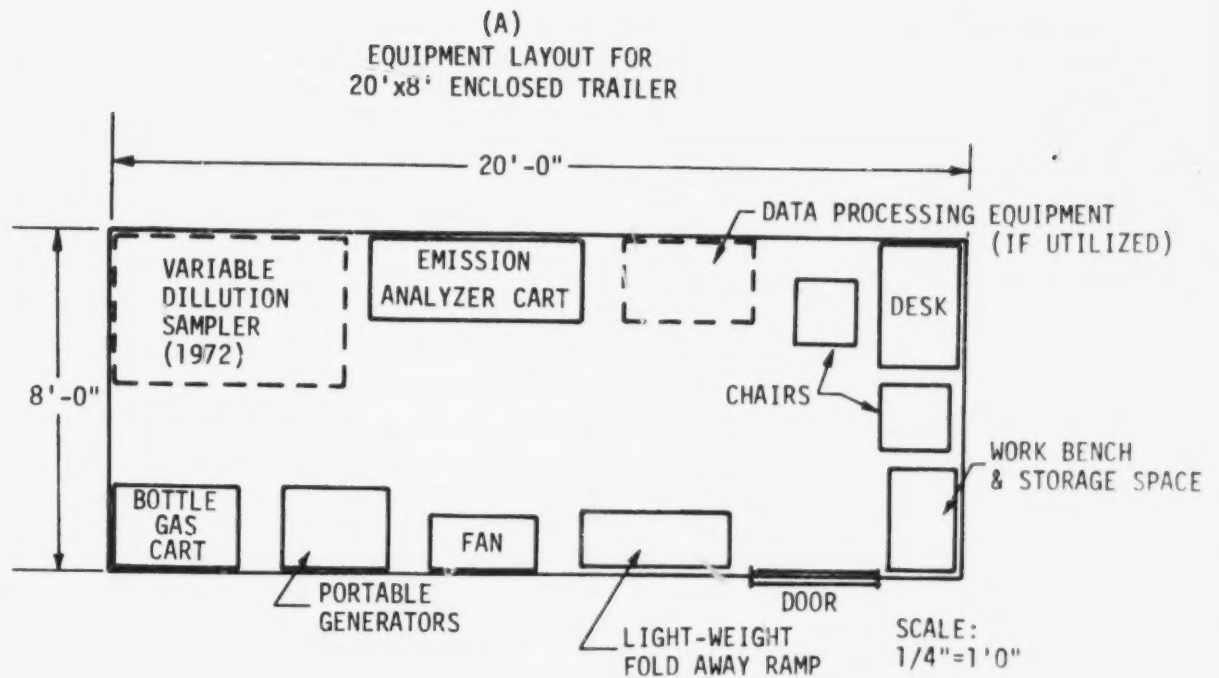
Data Acquisition Equipment Requirement

A surveillance program data acquisition system has been studied to define approximate costs and errors. To establish design criteria for this study, an approximate level of testing in a given region was assumed based on the data presented in the preceding sections. The criteria and assumptions made in this study are summarized below. They can generally be changed significantly without affecting the final recommendations.

- The surveillance program is to be initiated on a regional basis.
- The surveillance regional data system will have a growth capability to acquire data on up to 10,000 vehicles/year (250 vehicles/model year x 10 years x 4 vehicle tests per year).
- The test procedures per vehicle will involve from three to nine Federal cycle replications. The time required (13 to 30 minutes) per vehicle will depend on the test procedure.
- The flow per lane is estimated on the basis of a 6½ hour workday (allowance of 1½ hours for setting up and closing of site, dead time between vehicles tested and coffee breaks).

FIGURE 3-26

MOBILE UNIT



SKETCHES B & C ARE DIFFERENT CONFIGURATIONS FOR DYNAMOMETER TRAILER REQUIREMENTS. (NOT TO SCALE)

FIGURE 3-27

SURVEILLANCE STATION - EQUIPMENT STORED OVERNIGHT

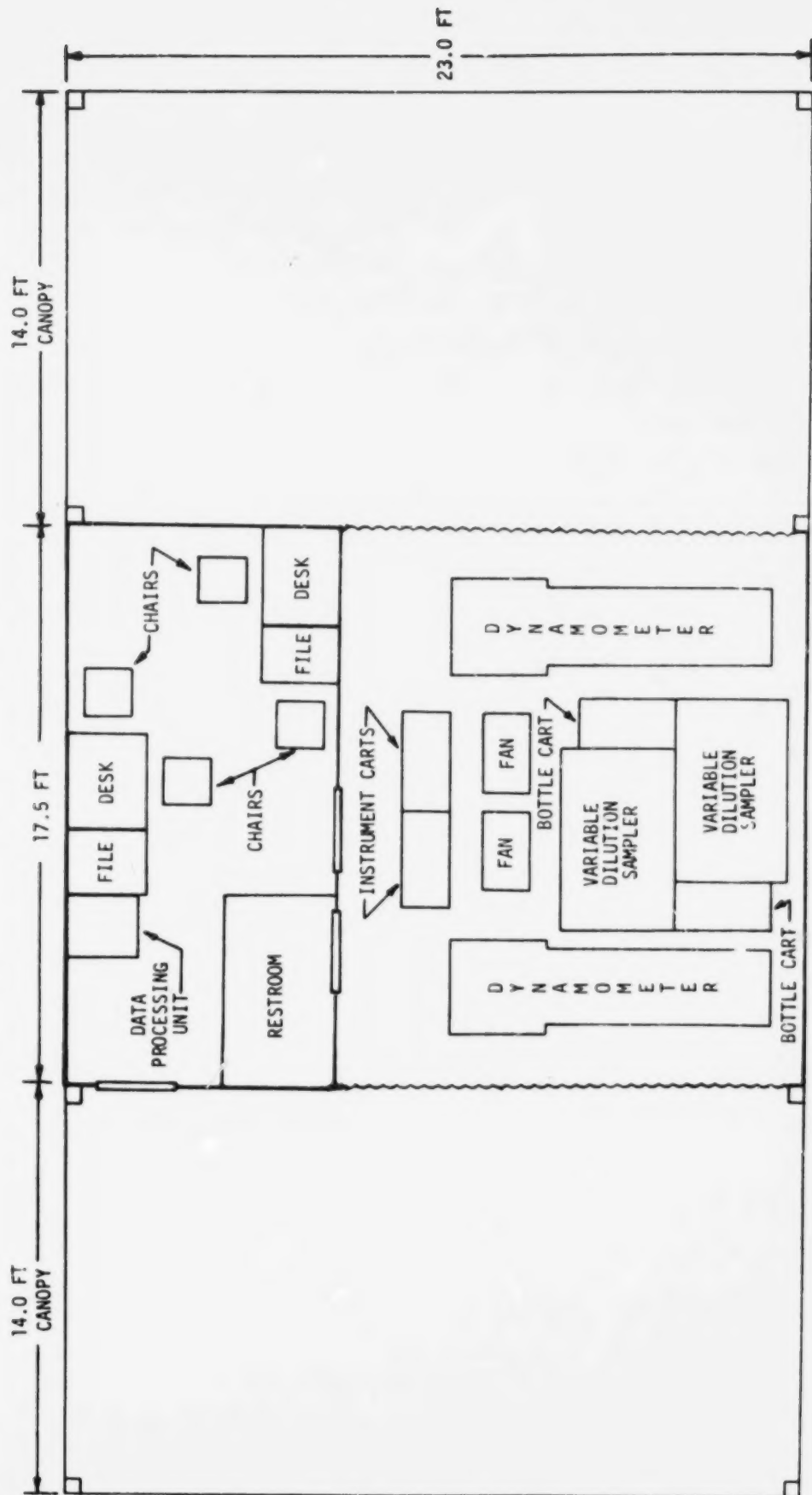
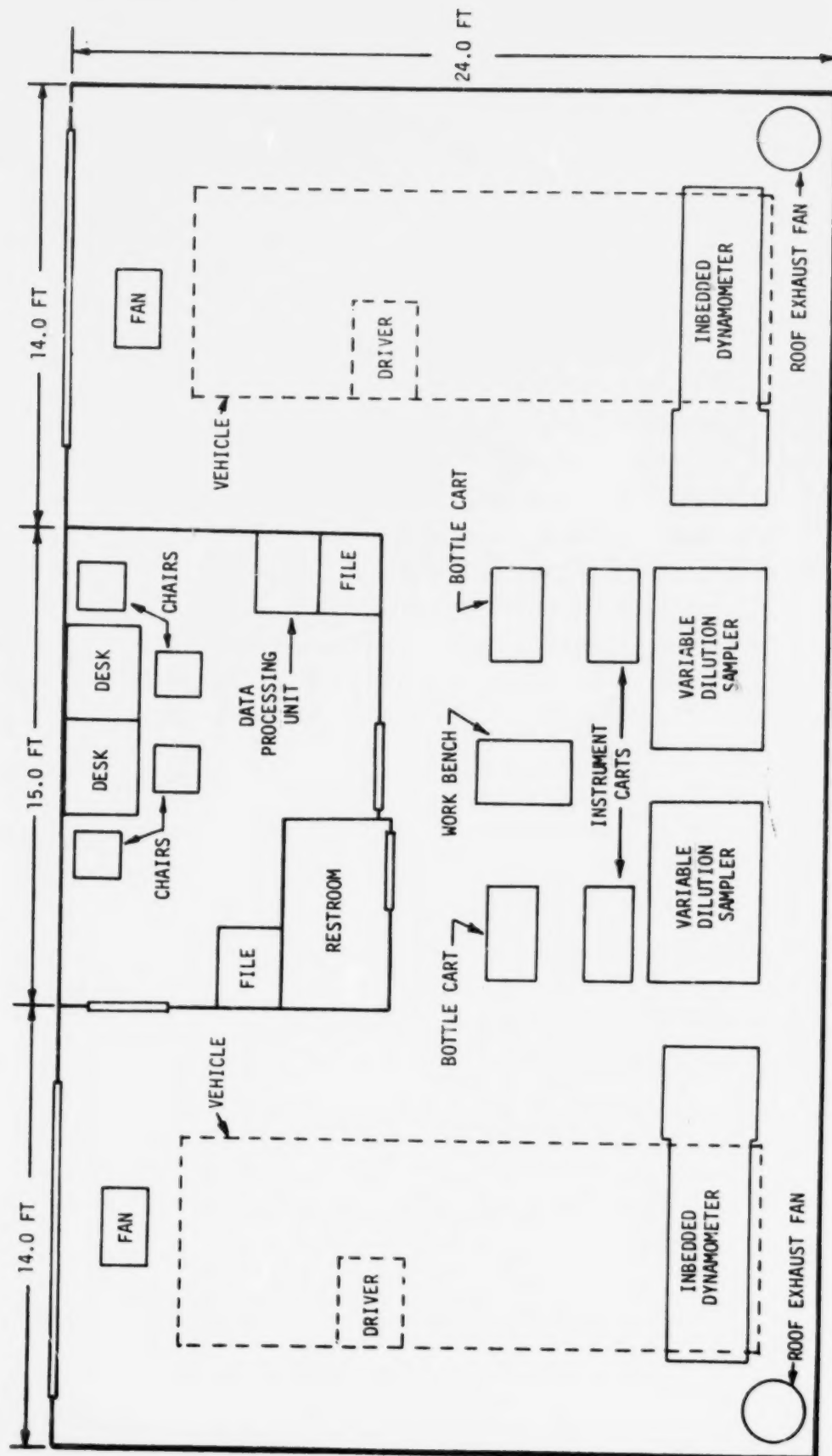


FIGURE 3-28

TOTALLY ENCLOSED SURVEILLANCE STATION



- The total flow per lane/year will be approximately 3000 to 7500 vehicles for 245 work days per year again depending upon the selected test procedure.
- Each surveillance region is assumed to have one of the following test site configurations which depend on the specific program to be implemented: Two mobile units - one lane each (hot cycle program); or one mobile unit and one fixed station - total of three lanes (accelerated temperature conditioning program); or one fixed station with three to four lanes (full Federal procedure program).
- The system must be compatible with both volume and mass sampling and should not be made obsolete or inefficient with changes in either procedure.

The degree of data processing to be performed on-site is contingent on:

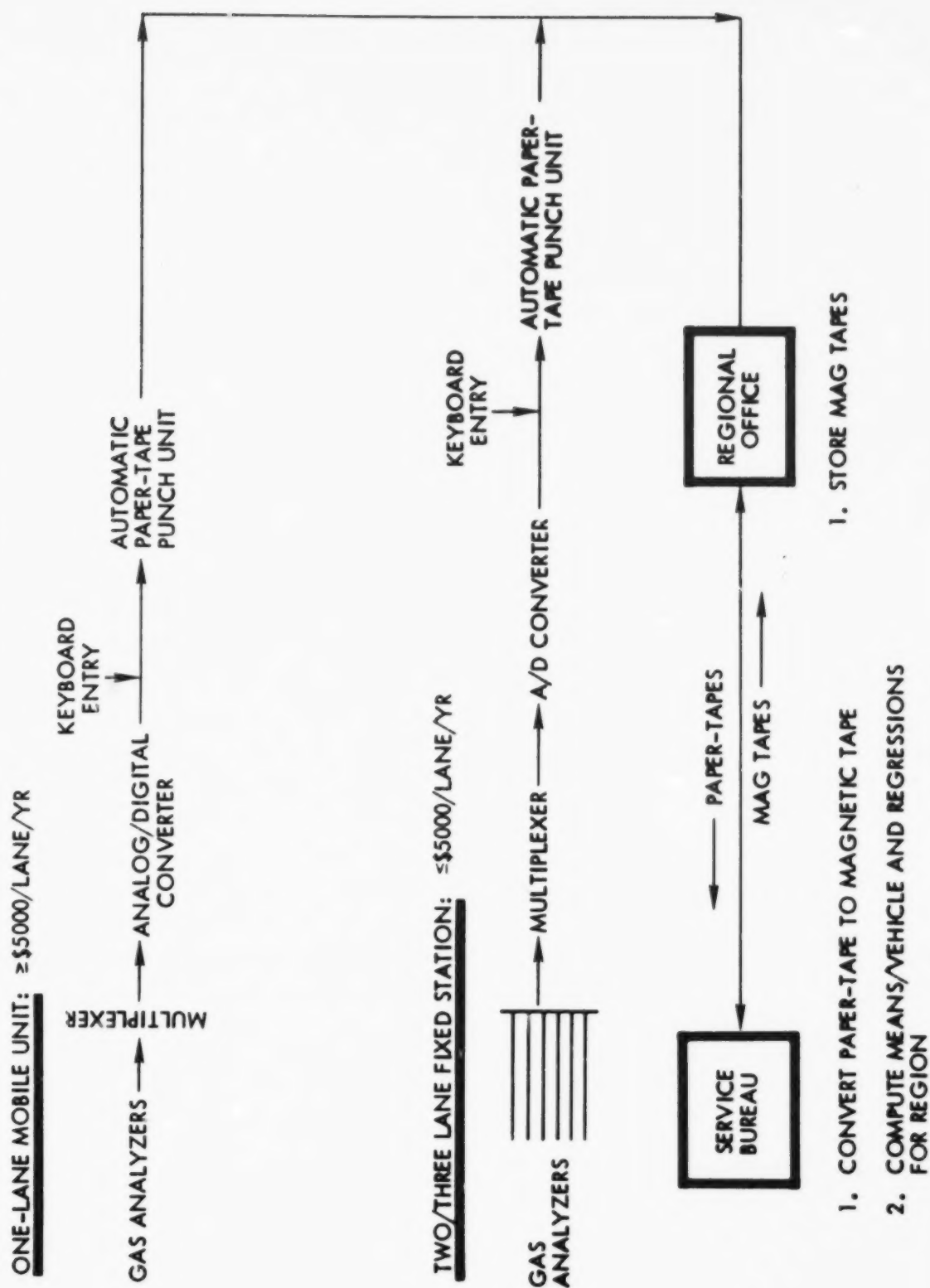
- The throughput of vehicles and corresponding justification for a small, on-site special-purpose computer.
- The requirement to take corrective action in real-time (i.e., on-site).

For the assumptions listed above and based upon realistic vehicle throughputs an on-site computer is probably not warranted, particularly as abatement decisions would not be made at the surveillance site. Therefore, it appears that a compact data output format suitable for inexpensive, temporary data storage is the maximum requirement for an on-site data acquisition system. This system is compatible with both mass and volume sampling. The following subsystems (Figure 3-29) are proposed for transforming the gas analyzer analog signal to the temporary storage media--an analog integrator-multiplexer, A/D converter, keyboard entry and automatic paper tape punch. The acquisition system performs the mode emission integrations using the analyzer analog signal which is then multiplexed to a single channel. The output of the multiplexer is stacked emissions data either for each cycle mode or bag.

Sixteen digits for each bag or mode of the test cycle are required:

HC - XXX (4)
 CO - X·XX (4)
 NO_x - XXXX (4)
 CO₂ - XX·X (4)

FIGURE 3-29
SURVEILLANCE PROGRAM DATA ACQUISITION SYSTEM



A keyboard entry is provided to enter pertinent vehicle and instrumentation data associated with the test run. Vehicle identification number (assigned by regional office), mileage, ambient, and instrument data requires 30 digits:

Mileage	- XXX XXX (6)
Identification No.	- XXX XXX (6)
Instrument Nos.	- XX XX XX XX (8)
Block Temperature	- XXX (3)
Ambient Temperature	- XXX (3)
Humidity	- XX (2)
Pressure	- XXX (3)

Instrument numbers are required for calibration curve lookup to convert the analog bag or mode data to engineering units at the central computer. The mode data are also weighted during this operation. Ambient data are required if NO or mass samples are being taken. The data flow for several test procedures is shown in Figure 3-29. The tapes are forwarded to the regional office, which, in turn, interacts with the Service Bureau. Depending on whether mode, mass, or both procedures are being used in the surveillance program, the appropriate software for converting to engineering units, weighting, calculating and statistically analyzing is filed at the central processor. This software is easily modified by the data user with no hardware impact on the field equipment. Therefore, a highly flexible, cost-effective data acquisition system results.

A cost breakdown for the above data processing equipment is as follows:

- Analog/digital converter (Astrodata Unit No. 3900) = \$1.75 K
- Keyboard entry = 0.5 K
- Analog Integrator (3 channels) = 2.4 K
- Automatic paper-tape punch unit (2. and 3. above
supplied per Digital Equipment Corporation) = 1.5 K
Each Unit \$6.1 K

Regional office costs assuming all data are reduced at a service bureau include:

- Converting paper to magnetic tape at \$60/hour (night rate). For two rolls per week at a conversion speed of 5 rolls/hour, the annual cost is:

$$50 \text{ weeks} \times \frac{2 \text{ rolls/week}}{5 \text{ rolls/hour}} \times \$60/\text{hour} = \$1.2 \text{ K}$$

- Central computing time to calculate vehicle emission level means and various monthly regressions required is 30 minutes/month. At a rate of \$850/hour (night rate), the annual cost is \$5.1 K (per Control Data Corporation).
- Initial software programming at a cost of \$15.0 K.

The estimated system error for this acquisition system exclusive of the analyzer is $\pm 2.0\%$ of full scale. This error component is small relative to emission measurement related errors.

4.0 SYSTEM MODEL

This section describes the system model and computer program which were developed for use in defining an optimum vehicle surveillance program. The computer program determines the confidences with which automobile emissions measurements can be made using selected procedures as well as the costs involved to establish and operate the required surveillance monitoring system. Test procedure and facility configurational variables which are subject to optimization include:

- Procedures for temperature conditioning a vehicle power train prior to test
- Driving cycle replications
- Test population sample size
- Procedures for vehicle acquisition
- Number and type of testing stations.

The computer program predicts the effect of these variables on the variance of emission measurements as well as upon surveillance program cost. The variance of four types of exhaust emissions can be predicted by the program: hydrocarbons, carbon monoxide, oxides of nitrogen, and carbon dioxide. Only the first three will be considered in the work reported here. The errors in predicting emission levels are expressed in terms of the variance about the mean emission level and are reported as the square of the units in which the emissions are measured.

Where a truncated emission test procedure (a procedure involving less than the full Federal test procedure) is used, a separate experiment is assumed to be run during the course of the surveillance program to obtain the required empirical data to relate the emission measured with the shorter procedure to those which would have been determined by a full Federal test. The error and cost impact of this added procedure is evaluated.

Figure 4-1 indicates the major subroutines of the surveillance computer program. Subroutines are present to calculate the major measurement errors involved in a surveillance program. Operations and cost subroutines also are included. Each subroutine listed in Figure 4-1 is discussed in the following sections.

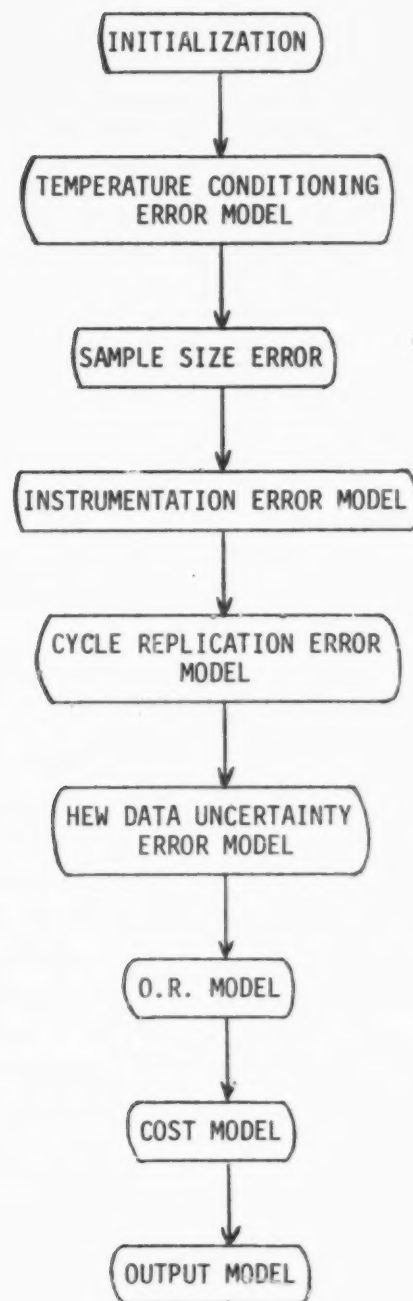


FIGURE 4-1
SURVEILLANCE EMISSION PROGRAM STRUCTURE

4.1 Temperature Conditioning Error Model

Three different power train temperature conditioning procedures can be simulated using the temperature conditioning error model. The three options are shown in the diagram of Figure 4-2. A glossary of terms used in the computer program is presented at the end of the section. If the index I is set equal to one then the model determines the errors associated with using a hot start emissions test on vehicles which are temperature conditioned to an initial steady-state operating temperature. The error incurred with this procedure is caused by the uncertainty in predicting the equivalent emission level which would have been determined by a full Federal test. The error computation is based on data supplied by the Environmental Protection Agency (EPA) and was derived by comparing hot cycle emission data and composite emission data.

$$\bar{K} = \frac{\sum_{i=1}^n e_{iF} - e_{i_{hot}}}{n} \quad (4-1)$$

The component errors of Equation (4-1) are given by

$$\sigma_{comp}^2 \equiv \sigma_{hot}^2 + \sigma_K^2 \quad (4-2)$$

where

$$\sigma_K^2 = \text{variance (or error) caused by performing the correction on } \bar{e}_{hot} \text{ with variance } \sigma_{hot}^2$$

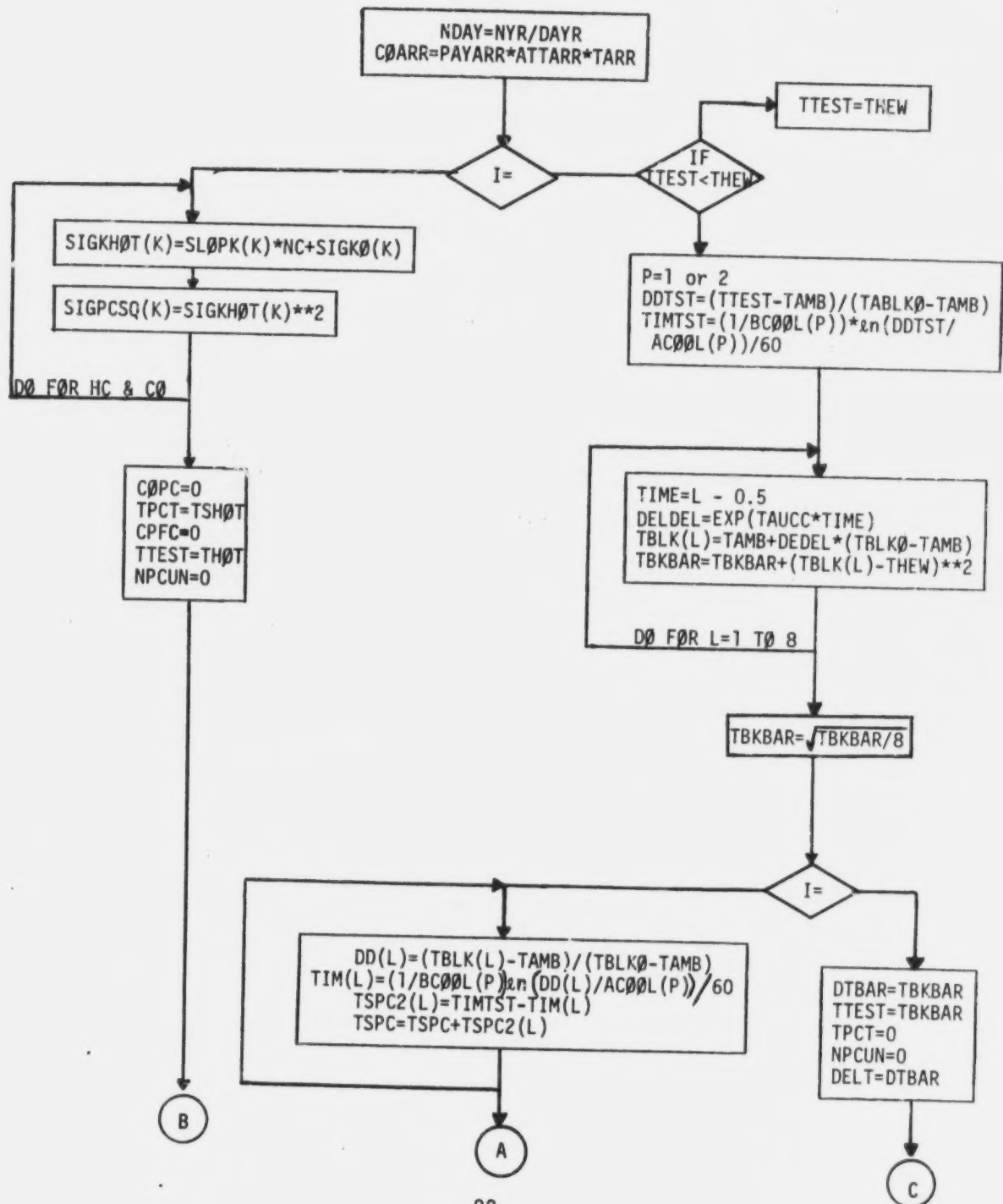
$$e_{iF} = \text{individual vehicle Federal emissions}$$

$$e_{i_{hot}} = \text{individual vehicle hot cycle mission}$$

$$n = \text{number of vehicles tested}$$

The second temperature conditioning option (I=2) simulates temperature conditioning procedures in which the engine block temperature is reduced to a specified value by means of either forced air cooling (P=1) or forced air plus water recirculation cooling (P=2). Basic cooling curves for

FIGURE 4-2
PRECONDITIONING ERROR MODEL



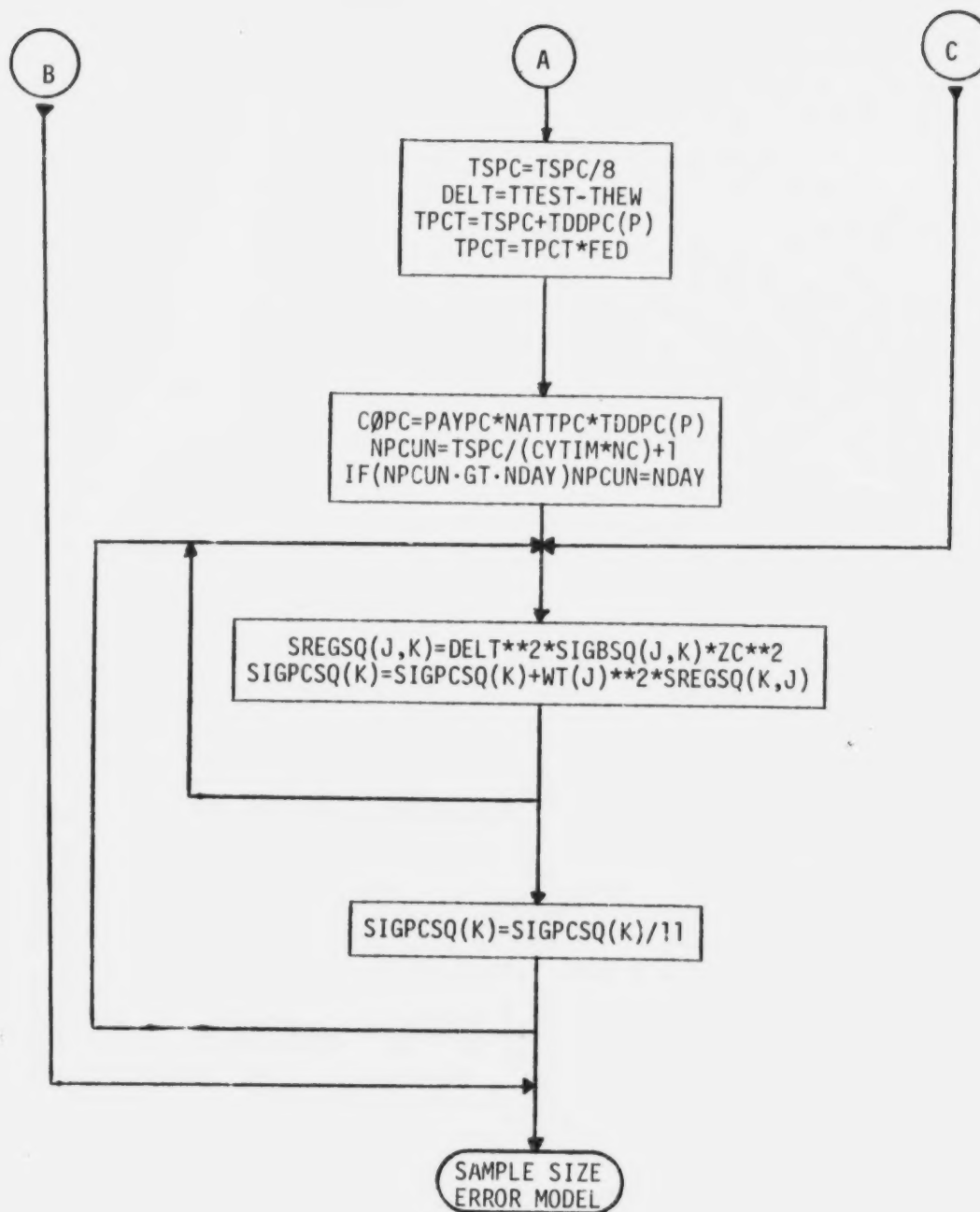


FIGURE 4-2
PRECONDITIONING ERROR MODEL (CONT.)

these two procedures were obtained by exponential curve-fitting the data obtained from the temperature conditioning experiment presented in Section 3.0. The curves are of the form:

$$T_B = T_{AMB} + (T_{BI} - T_{AMB})Ae^{-Bt} \quad (4-3)$$

where

T_B	= block temperature ($^{\circ}F$)
T_{BI}	= initial block temperature ($^{\circ}F$)
T_{AMB}	= ambient temperature ($^{\circ}F$)
t	= time in minutes
A	= curve-fit coefficient
B	= time constant (1/min.)

Values of A and B for the two accelerated power train cooling procedures are shown below:

	<u>A</u>	<u>B</u>
Forced air cooling	1.185	0.0133
Forced air plus water recirculation cooling	0.877	0.0293

The initial block temperature to be used in equation 4-3 to predict the time required to cool power trains to a specified temperature state are:

- A block temperature determined using the expected engine block temperature of cars arriving at the test station and the average car storage duration at the test site before initiating power train temperature conditioning.
- A steady-state block temperature typical of urban operation assuming cars are taken off the street and almost immediately are subjected to temperature conditioning.

The third temperature conditioning alternative (I=3) simulates testing vehicles in their "as-received" condition following an arbitrary period of normal cooling in ambient air. Where a normal cool-down occurs,

the following relationship is used to predict block temperature

$$T_B = T_{AMB} + (T_{BI} - T_{AMB}) e^{-.139t} \quad (4-4)$$

where the units of time are given in hours.

Errors are introduced in the second and third temperature conditioning alternatives because of variation in the power train temperature at the start of emission testing. Also, as in the first alternative, an error is introduced with the second and third alternatives as a result of testing at temperatures other than that prescribed by the Federal procedure. The prediction of the emission level which would have resulted from a Federal test based upon performing the test at different initial power train temperature states is made by means of linear regression of the temperature conditioning experiment data.

$$\bar{e}_F = \bar{e}(T) + b\Delta T \quad (4-5)$$

An analysis of errors yields:

$$\sigma_F^2 = \sigma^2(T) + (\Delta T \sigma_b)^2 \quad (4-6)$$

where

ΔT = Temperature difference between the test and Federal procedures

$\bar{e}_F$ = Mean emission value which would have been predicted had a full Federal procedure been performed

$\bar{e}(T)$ = Mean emission value resulting from testing at temperature state, T

$b \pm \sigma_b^2$ = Temperature correction factor and its variance

$\sigma^2(T)$ = Standard estimate of error at temperature T

σ_F^2 = Error estimate for the Federal procedure caused by the correction procedure

The regression analysis was performed on data describing the individual power trains studied during the temperature conditioning experiments. Although only 11 generically different power trains were tested, it

is tacitly assumed that the data for this limited population accurately predict emission-temperature sensitivity although not necessarily absolute emission values. Therefore, the only component of error considered in the model is that caused by a poor prediction of the slope coefficient, σ_b . The variance, $\sigma^2(T)$ is essentially a within-vehicle error and is treated in the sections which follow. The justification that $\sigma^2(T)$ is a within-vehicle error lies in the fact that for the case where $\Delta T=0$, the error in the prediction caused by vehicle initial temperature state must be zero since the case represents the Federal test.

Two other factors have been considered in establishing an error model:

- A confidence statement on the error in the slope coefficient
- A weighting factor for each power train to account for its frequency of occurrence in a general population.

The confidence level is introduced by multiplying σ_F by the two-sided test limit (Z_c) at the desired confidence level (Reference 7). The weighting factors (W_i) for the individual power trains were found by matching their attributes to those of the vehicles given in Reference 4. These factors represent the proportion of each power train found in a general population. Values for W_i and $\sigma_{b_i}^2$ were calculated and are used in the program, Table 4-1.

The final expression for the error is given by:

$$\sigma_{PC_i}^2 = \frac{\sum_{i=1}^{11} (W_i \cdot \Delta T \cdot \sigma_{B_i} \cdot Z_c)^2}{11} \quad (4-7)$$

where

σ_{PC}^2 = error caused by temperature conditioning.

The values of Z_c used are:

	<u>Confidence Level</u>		
	<u>90%</u>	<u>95%</u>	<u>99%</u>
Z_c	1.812	2.30	3.169

TABLE 4-1. WEIGHTING FACTORS AND EMISSION VARIANCE
CAUSED BY BLOCK TEMPERATURE SENSITIVITY

POWER TRAIN VEHICLE CID	66 PLY 318	66 CHEV 327	66 CHEV 283	67 FORD 390	69 FORD 302	68 FORD 390	66 DODGE 383	66 FORD 200	68 BUICK 430	68 FORD 302	69 PLY 225
W_1	.045	.223	.104	.073	.05	.082	.065	.068	.182	.052	.056
$\sigma_{B_{CO}}^2$	9×10^{-6}	4×10^{-5}	5×10^{-6}	5×10^{-5}	5×10^{-6}	3×10^{-6}	9×10^{-6}	7×10^{-5}	1.1×10^{-4}	1×10^{-6}	4×10^{-6}
$\sigma_{B_{HC}}^2$	.0571	1.4078	.6028	.2421	1.5203	.128	.3719	1.2937	.1318	.0296	.065

When Flag I is set equal to 2, the full Federal test may be simulated by specifying that the test temperature be within the range of the Federal test and by setting the number of cycles replications to seven. Two other model adjustments must be made to reflect the Federal test. Because of the 12-hour cold soak requirement, an air-conditioned structure must be available and, therefore, its cost must be considered in the cost model. In addition, vehicle acquisition costs must reflect the prolonged period of time during which the owner is without his vehicle. The acquisition cost thus must include the cost of a loan car, lease car, or other equivalent vehicle substitution. The cost model is discussed in detail in Section 4.7.

4.2 Sample Size Error Model

The emission data supplied by EPA from their surveillance program was used as described in Section 3.0 to estimate emission means and variances for samples of various sizes. Variability determined using the EPA emission data was caused by the effect of sample size as well as by within-car variability. To determine the error component caused by sample size the within-car error must be determined and subtracted from the total error determined using the EPA data. An estimate of within-car variability was made for each of the 11 vehicle power trains studied in the temperature conditioning experiment based on the scatter of the emissions test data about the regression line which removed the effect of initial power train temperature state, Table 3-3. A within-car error then was calculated by pooling the variances determined for each car. The equation used to pool variances is of the form:

$$\sigma_{\text{pool}}^2 = \frac{(n_1-1)(S_1)^2 + (n_2-1)(S_2)^2 + \dots + (n_{11}-1)(S_{11})^2}{\sum_{i=1}^{11} (n_i - 2)} \quad (4-8)$$

(Reference 7)

The error in estimating the population variance is then found by using the chi-squared distribution for a given confidence level

$$\sigma_{ss}^2 = ((SS-1) \cdot (S_{EE})^2/x^2) - \sigma_{pool}^2 \quad (4-9)$$

Equation 4-10 is an approximation to the chi-squared distribution for sample sizes greater than 30, Reference 8.

$$x^2 = \frac{1}{2} (Zn + \sqrt{2(SS-1)-1})^2 \quad (4-10)$$

In the above equations,

- σ_{pool}^2 = pooled variance of all 11 power trains
- n_i = number of tests to which each power train is subjected
- S_i^2 = individual power train within-car variance
- SS = sample size
- S_{EE}^2 = total error (variance) from EPA data, Figure 3-20.
- x^2 = chi-squared distribution

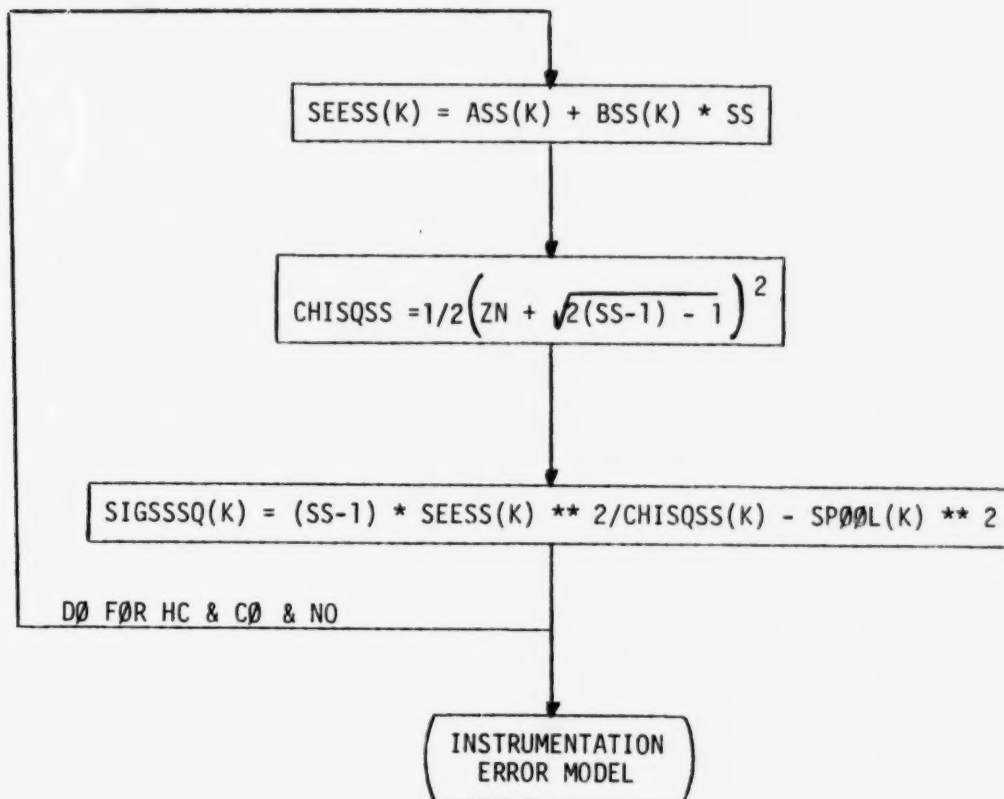
where

- Zn = -2.328 for 99% confidence level
- 1.645 for 95% confidence level
- 1.283 for 90% confidence level

The sample size error model is shown in Figure 4-3.

It should be noted that a one-sided confidence test is applied and results in a worst-case estimate of σ_{ss}^2 . The effects of selecting a two-sided confidence test would be to read the 95% level of a two-sided test as equivalent to a 90% level for a one-sided test.

FIGURE 4-3
SAMPLE SIZE ERROR MODEL



INPUTS:

	<u>Hot Composite</u>		<u>Cold Composite</u>	
ASS(K) = composite sample size error	HC=85	CO=.925	HC=97	CO=.80
BSS(K) = slope coefficient for SS error	HC=0	CO=0	HC=0	CO=0
SP00L(K) = pooled within car error	HC=27.02	CO=.21	HC=28.9	CO=.213
ZN = standard normal 90% = 95% = 99%				

4.3 Instrumentation Error Model

Instrumentation error involves errors of accuracy and precision in both the analyzer and recorder. Error values vary with the type of instrumentation and the manufacturer. Only instruments of the non dispersive infrared type are considered to be appropriate for use in a surveillance program. Based on the discussion of instrument errors in Section 3.0, only the precision component of error is used in the error model, Figure 4-4. Since most NDIR type instruments have similar precision errors, the instrumentation error model contains only a single set of representative error values. Instrument precision standard errors are 6.8 ppm and 0.043% for HC and CO, respectively.

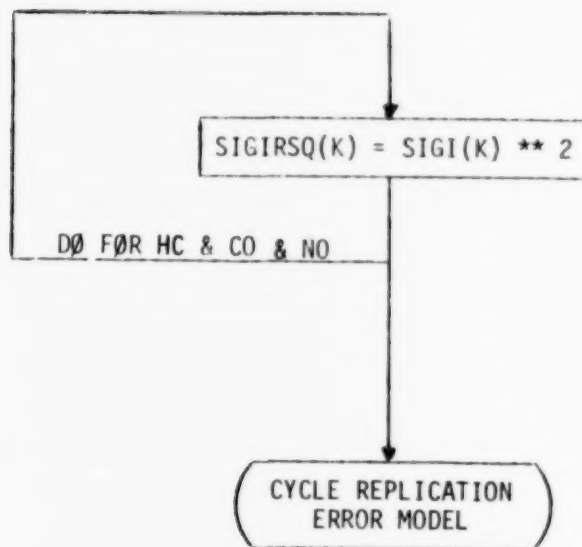
4.4 Cycle Replication Error Model

The repeatability of the duty cycle as well as of the vehicle's inherent variability make up the cycle replication error model. The within-car error discussed in the sample size error model contains the replication error as well as the error resulting from the instrumentation used in generating the data. Subtracting the instrumentation error from the within-car error yields an estimate of the cycle replication error which is modeled in Figure 4-5.

The data used to compute the within-car variance were obtained from the temperature conditioning experiment. Only the data from the hot cycle tests were used in order to avoid errors caused by temperature effects, which are separately accounted for in the temperature conditioning error model. The weighted variance for the eleven power trains was calculated using Equation 4-8.

The chi-squared distribution is employed to calculate the error at different numbers of replications and levels of confidence. The following values were used:

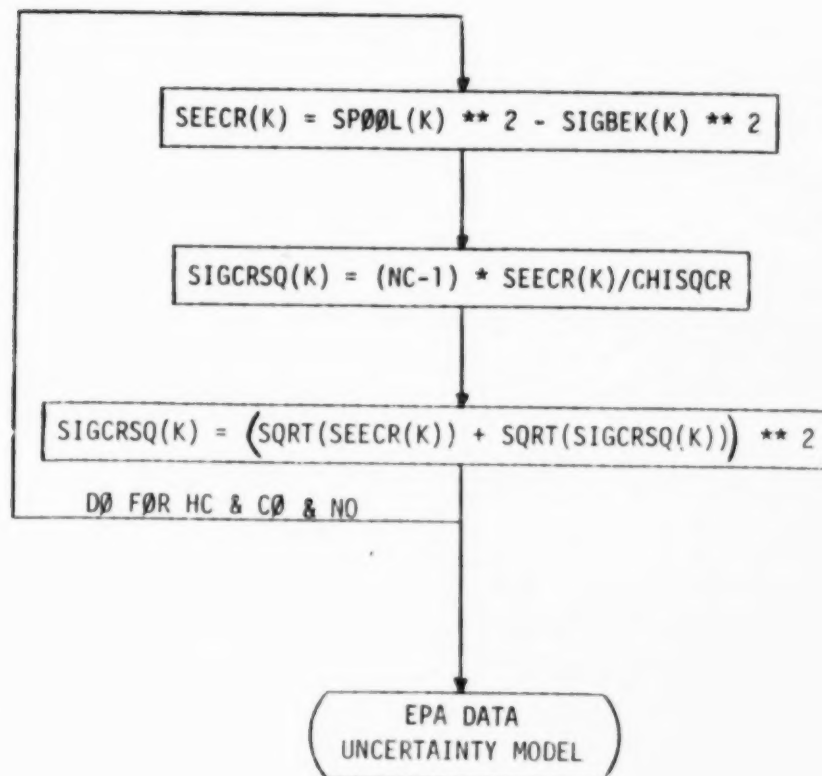
FIGURE 4-4
INSTRUMENTATION ERROR MODEL



INPUTS:

SIGI(K) = instrumentation error - HC: 6.8 ppm
CO: .9426%
NO: 14 ppm

FIGURE 4-5
CYCLE REPLICATION ERROR MODEL



INPUTS:

SP00L(K) = see sample size error model

SIGBEK(K) = original instrumentation error - HC: 6.8 ppm
CO: .0426%
NO: 14 ppm

<u>Number of Cycles</u>	<u>90% Conf.</u>	<u>Chi-Squared 95% Conf.</u>	<u>99% Conf.</u>
2	0.016	0.004	0
3	0.211	0.103	0.020
4	0.584	0.352	0.115
5	1.064	0.711	0.297
6	1.61	1.15	0.554
7	2.20	1.64	0.872

The values of chi-squared are those of a one-sided test as given in Reference 8.

4.5 EPA Data Uncertainty Error Model

Because the data to which all emissions are to be correlated (EPA data) represent only the 1968 model year, a correction must be made to the total estimated standard error to reflect the confidence with which the 1968 models represent the entire population. The following relation yields the variance of the population mean as made up of the individual model years means.

$$\begin{aligned} \sigma_{POP}^2 = & \frac{W_{66}(\overline{E_{66}} - \overline{E_{POP}})^2}{n-1} + W_{67} \frac{(\overline{E_{67}} - \overline{E_{POP}})^2}{n-1} + W_{68} \frac{(\overline{E_{68}} - \overline{E_{POP}})^2}{n-1} \\ & + W_{69} \frac{(\overline{E_{69}} - \overline{E_{POP}})^2}{n-1} \end{aligned} \quad (4-11)$$

The year-to-year mean emissions data used were that of the California ARB for hot replicated cycles, Reference 4.

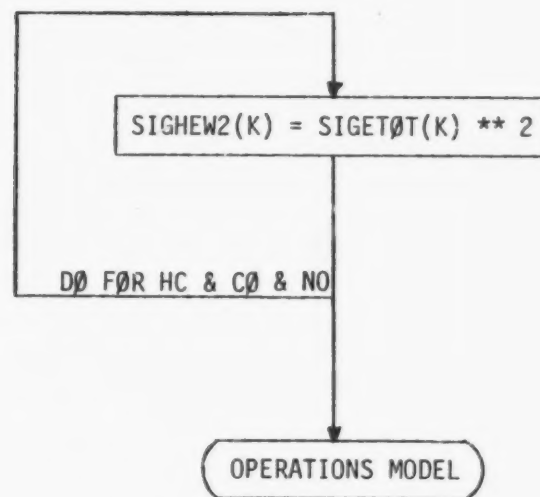
$\overline{E_i}$ = mean emission value of each model-year

W_i = weight factor of each model-year

n = number of model-years

The EPA data uncertainty error model is shown in Figure 4-6.

FIGURE 4-6
HEW DATA UNCERTAINTY ERROR MODEL



INPUTS:

$SIGETOT(K) = 20.2, .194$

4.6 Operations Model

This model, shown in Figure 4-7, computes the number of dynamometers required in a surveillance station. For a mobile station, it computes the number of trailers required and, finally, it calculates the number of temperature conditioning units necessary for those strategies which call for vehicle temperature conditioning; if no temperature conditioning is required the number of temperature conditioning units is zero.

The labor hours for both the temperature conditioning and emissions test procedures are calculated on a per-test basis as part of the error model subroutine they support. The two temperature conditioning procedures, as noted in Section 3.0, require 20 and 10 labor minutes for forced air cooling with and without cooling water recirculation, respectively.

The emission measurement procedure time is composed of two components:

- A fixed time associated with pre- and post-test preparation
- A variable time which is proportional to the number of replicated driving cycles.

The equation for this model is:

$$T_m = N (T_{\text{fixed}} + NCAT_{\text{CYCLE}}) \quad (4-12)$$

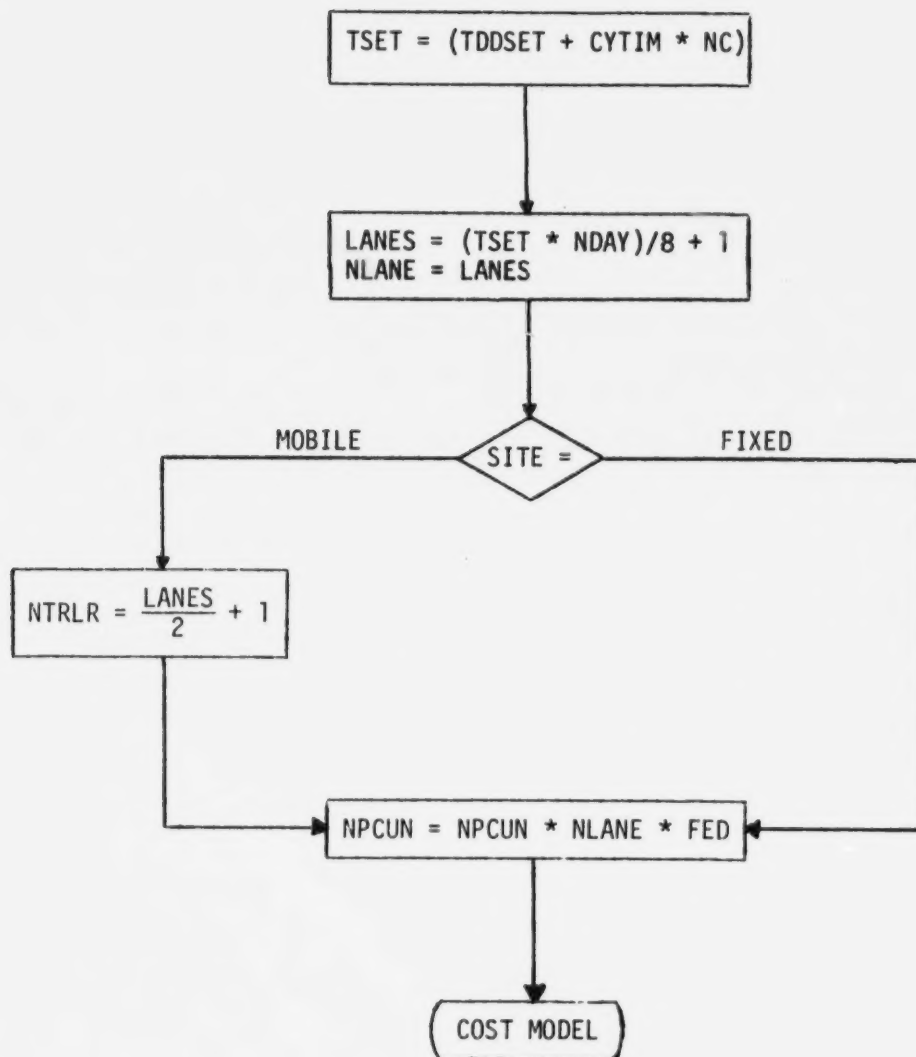
where:

- N = total average number of personnel manning test lane, 2.5
- T_m = total labor time to perform the measurement procedure
- T_{fixed} = pre- and post-test preparation, 5 minutes (Figure 3-23)
- T_{CYCLE} = time to perform one Federal driving cycle, 2.5 minutes
- NC = number of replicated driving cycles

4.7 Cost Model

The flow diagram for the cost model is shown in Figure 4-8. The following costs are computed by the model:

FIGURE 4-7
OPERATIONS MODEL



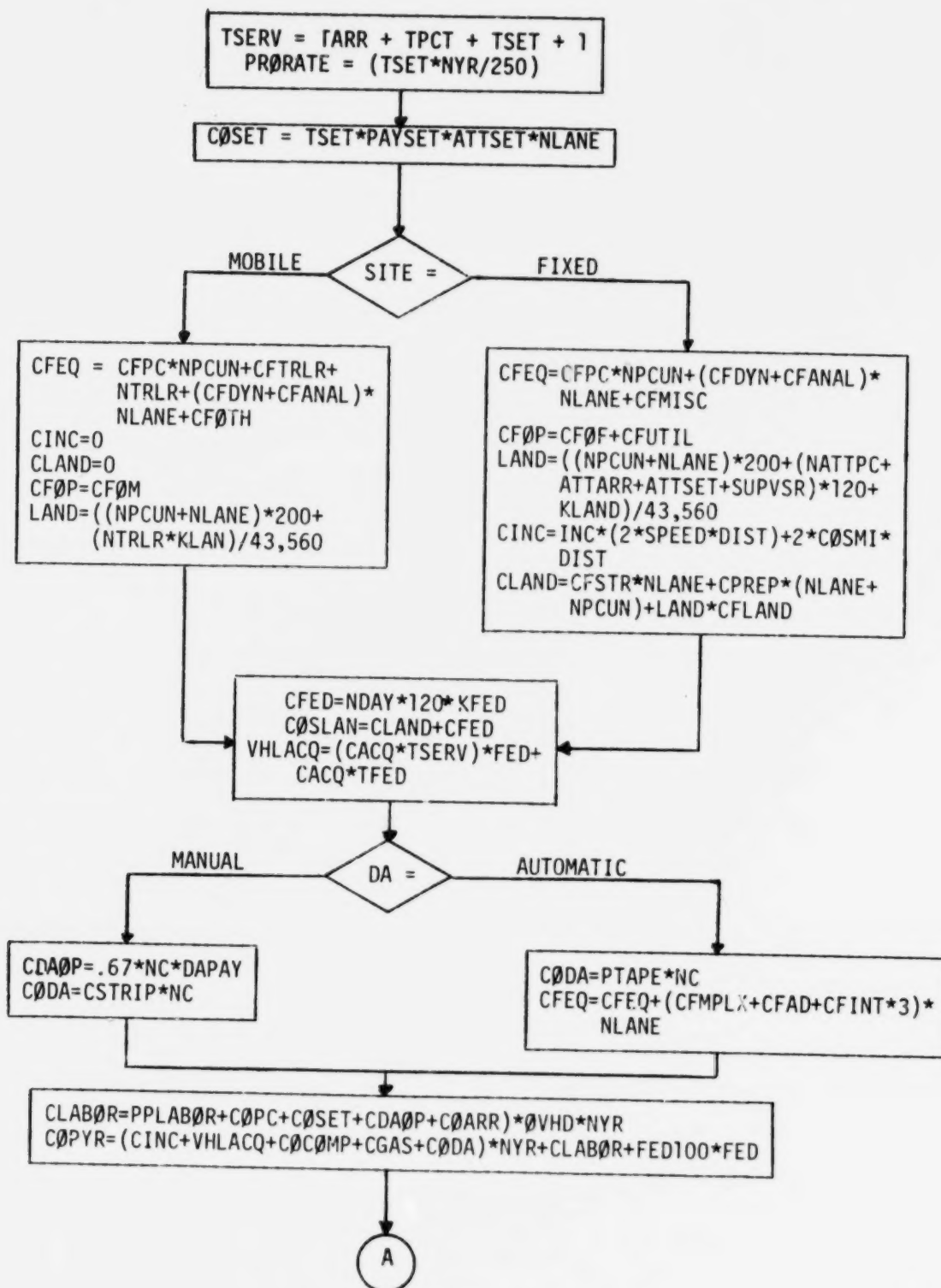
INPUTS:

TDDSET = TIME DELAY DURING EMISSION TEST (.078 hours)

FED - FLAG = 0 for Federal test
= 1 other test

FIGURE 4-8

COST MODEL



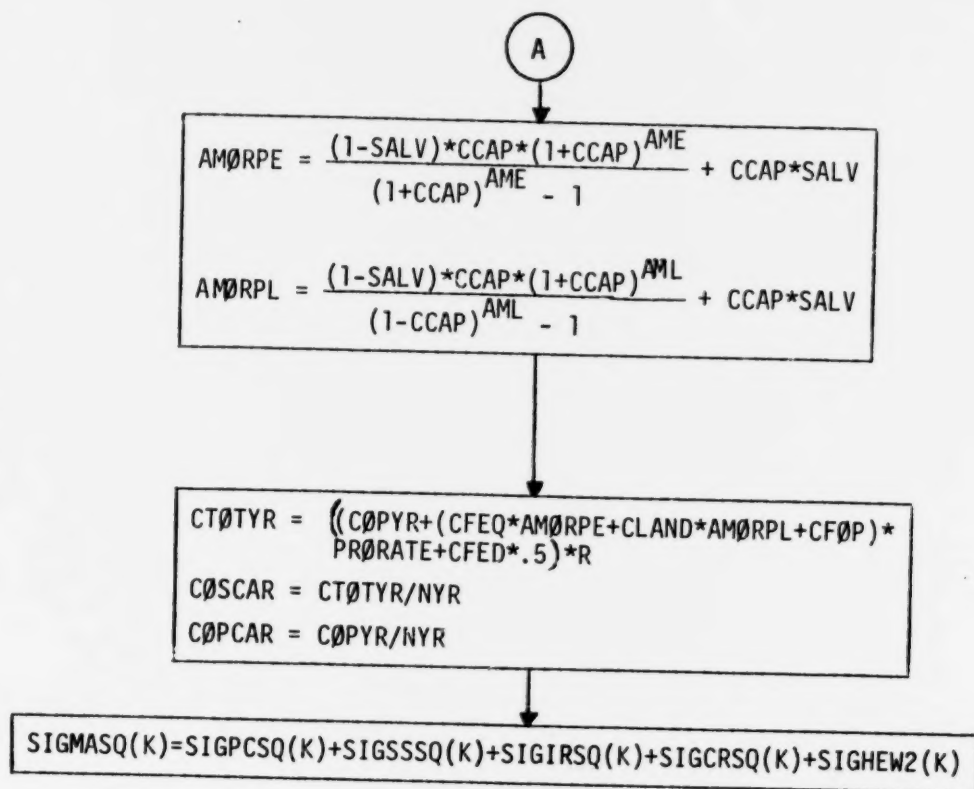


FIGURE 4-8 COST MODEL (Cont'd)

Direct Operating Costs:

Direct Labor

Calibration Gases

Computing

Data Acquisition & Reduction*

Vehicle Acquisition & Inconvenience

Indirect Operating Costs:**

Maintenance

Set-up & Shutdown

Training

Power

Dead Time

Station Positioning

Supplies

Capital Costs:**

Instrumentation

Dynamometer

Trailers

Structures

Land

Parking Area

Miscellaneous

*Discriminates between manual and automatic data acquisition & reduction.

****Discriminates** between mobile and fixed station.

All capital costs (equipment and instrumentation) are amortized. The amortization factors are functions of the cost of capital, salvage value as well as the amortization period. All costs either can be assigned to the surveillance activity or they can be prorated to surveillance based upon the fraction of total time the facility is used for this purpose. This latter procedure is used in the cases studied in Section 5.0 and hence it has been tacitly assumed that an alternate use for the facilities exists when they are not required for surveillance.

All direct labor costs are burdened with an overhead factor. The overhead factor, as used here, is an adjustment of the direct labor hours to account for such factors as:

- Nonproductive down time such as might occur when measurement system maintenance is being undertaken or when a test vehicle is not available
- Fringe benefits such as group insurance, retirement funds, savings plans, etc.
- General administration related to the project
- Direct labor costs associated with acquiring a test vehicle

The overhead factor does not include investment and fixed operational costs which are usually associated with a burden rate since the surveillance system cost sensitivity to these parameters is to be evaluated in the tradeoff studies.

The direct labor requirements for performing temperature conditioning and emissions measurements may be charged at different labor rates, if required.

SURVEILLANCE PROGRAM LIST OF VARIABLES

AMORPE	-	Equipment Amortization Factor
AMORPL	-	Land Amortization Factor
CDAOP	-	Manual Data Acquisition Hourly Rate, \$
CFED	-	Cost of Land Required for Federal Testing, \$
CFEQ	-	Fixed Cost of Equipment, \$
CFOP	-	Fixed Annual Operating Costs, \$
CFPC	-	Fixed Cost of Preconditioning Test Equipment, \$
CHISQSS	-	Chi Squared Function for Sample Size Error Computation
CINC	-	Vehicle Acquisition Inconvenience Cost, \$
CLABOR	-	Total Annual Labor Cost, \$
CLAND	-	Cost of Land, \$
CODA	-	Data Acquisition Materials Cost, \$
COPC	-	Preconditioning Test Operating Cost, \$
COPCAR	-	Annual Operating Cost Per Vehicle, \$
COPYR	-	Total Annual Operating Cost, \$
COSET	-	Emission Test Operating Cost, \$
COSCAR	-	Total Annual Cost Per Vehicle, \$
COSLAN	-	Total Land Cost, \$
CTOTYR	-	Total Annual Cost of Surveillance Program, \$
DD	-	Intermediate Variable in Preconditioning Time Computation
DDTST	-	Intermediate Variable in Engine Cooling Curve Calculation
DELDEL	-	Intermediate Variable in Engine Cooling Curve Calculation
DELT	-	Difference Between Test and Reference Temperatures, °F
LAND	-	Land Area Required for Surveillance Station, Acres
LANES	-	Number of Lanes for Emission Test
NDAY	-	Daily Number of Cars to be Tested
NLANE	-	Number of Lanes for Emission Test
NPCUN	-	Number of Preconditioning Units Required
NTRLR	-	Number of Trailers Required for Mobile Station
PRORATE	-	Station In-Use Time Used in Proration Calculations
SEECR	-	Cycle Replication Error Variance
SEESS	-	Sample Size Error Variance
SIGCRSQ	-	Squared Error Due to Cycle Replication
SIGHEW2	-	Squared Error of HEW Data Emission Estimate

SIGIRSQ	-	Squared Error Due to Instrumentation
SIGKHOT	-	Error Variance in Prediction from Hot Cycle to Composite Emission
SIGMASQ	-	Total Surveillance Test Error Estimate
SIGPCSQ	-	Squared Error Due to Preconditioning Test
SIGSSSQ	-	Squared Error Estimate Due to Sample Size
SREGSQ	-	Error Estimate Introduced by Regression Analysis of Individual Power Train Emissions
TBKBAR	-	Average Amount of Preconditioning, °F
TBLK	-	Engine Block Temperature, °F
TIM	-	Time Required to Precondition Engines at Given Temperatures, hours
TIME	-	Time Intervals at Which Natural Cooling is Computed, hours
TIMTST	-	Cooling Time from Arrival to Test Temperature, °F
TPCT	-	Preconditioning Test Duration, hours
TSERV	-	Total Service Time Per Vehicle, hours
TSET	-	Emission Test Duration, hours
TSPC2	-	Intermediate Variable in Preconditioning Time Computation
TTEST	-	Test Temperature, °F
VHLACQ	-	Acquisition Cost Per Vehicle, \$

5.0 SYSTEM MODEL SIMULATION RESULTS

The computerized systems model summarized in Section 4.0 and the data discussed in Section 3.0 were used to evaluate the relative merits of various procedural and configurational options available to a surveillance program. Table 5-1 presents a matrix of the cases studied and reported in this section. Mobile sites located on either industrial or public parking lots were investigated using a wide array of temperature conditioning procedures as well as emissions tests involving three different numbers of replications of the 7-mode cycle. Testing at permanent sites was studied using either the full Federal emission test procedure or an accelerated cool-down to a block water temperature of 100°F coupled with an emissions test involving five replications of the 7-mode cycle.

5.1 Error and Cost Sensitivity to Test Procedures

A mobile test station operating in an industrial parking lot was used as a base case to investigate surveillance program error and cost sensitivities to various procedural options. The following general assumptions apply:

- Surveillance program options are to be compared based upon the predicted standard errors at the 95% confidence level for exhaust emissions to the atmosphere from controlled 1966-68 vehicles.
- When a short duration emissions test procedure is used, Federal emissions test data are required from 100 vehicles to establish the bias and random error components of the correction factors which are applied to estimate Federal composite emissions.
- Testing is performed on a production line basis, labor dead times do not exceed those of Table 5-2.
- The cost of acquiring a vehicle for any procedure is \$2/hour retained; vehicles for the Federal test are held for 12 hours.
- An automatic data acquisition system is used. An additional \$4.50 would be required for each replication of the 7-mode cycle if the data were reduced manually.

In addition to the assumptions just listed, particular information was input into the model to specify components of error and cost. Temperature conditioning error and system cost data are summarized in Table 5-2.

TABLE 5-1
SUMMARY OF SURVEILLANCE PROCEDURES EVALUATED

Type Case No.	Inspection Station Description	Block Temperature at Start of Test, °F			Accelerated Cooling		Driving Cycle Replications
		As Received	Hot	Fan Air	Water Recirculation		
1	Mobile-Industrial Park- ing Lot	83-200	220			3, 5, 7	
2							
3				83			
4				90			
5				100			
6				110			
7							
8	Mobile-Industrial Park- ing Lot			83		3, 5, 7	
9				90			
10				100			
11				110			
12							
13	Stationary-Remote Site	83	220			5	
	Stationary-Remote Site (full Federal Procedure)					7	

INPUTS TO TEMPERATURE CONDITIONING OPERATIONS MODELS

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TABLE 5-2
INPUTS TO TEMPERATURE CONDITIONING OPERATIONS MODELS (CONTINUED)

CFOF - Fixed annual operating cost for fixed site - 5219\$
 CFOM - Fixed annual operating cost for mobile site - 8153\$
 CFOTH - Miscellaneous fixed costs for mobile site - 0
 CFPC - Cost of temperature conditioning equipment per unit - 200\$
 CFSTR - Cost of structure per lane - 5000\$
 CFTRLR - Cost of mobile trailer - 25,000\$
 CFUTIL - Utilities cost per year - 3000\$
 CGAS - Cost of calibration gases per vehicle - 9\$
 COCOMP - Computing cost per vehicle - 0.50\$
 COSMI - Inconvenience cost per mile - 0.10\$/mi
 CPREP - Lane preparation costs - 400\$/lane
 CSTRIP - Strip chart cost per cycle - 0.45\$
 DAPAY - Pay rate for manual data reduction - 4.9\$/hr
 DIST - Mean distance traveled to station - 15 miles
 FED100 - Cost of 100 Federal tests - 4275\$
 INC - Inconvenience cost per vehicle - 2\$/hr
 KFED - Cost of structure for Federal test - 13\$/ft²
 KLAN - Land area per trailer - 600 ft²
 KLAND - Additional land for fixed site - 0
 OVHD - Overhead burdening factor - 1.8
 PPLABOR - Pre-post test labor - 0 (lumped into set)
 PTAPE - Cost of paper tape per cycle - 0.05\$
 SALV - Salvage value of property - 5%
 SUPVSR - Supervisor - 1
 PAYSET - Pay rate of test attendants - 4.9\$/hr
 TFED - Cold soak period for Federal test - 12 hours

The estimated standard error about the predicted mean level of the exhaust emissions measurements, σ_T , is shown in Figures 5-1 through 5-3 as a function of the number of replicated 7-mode cycles used in the emissions test as well as the size of the test population. Curves are shown for three temperature conditioning options. The standard error is very much more sensitive to the number of replicated cycles than to sample size within the ranges of these variables studied. Clearly increasing the sample size beyond 250 to 300 vehicles has almost no effect upon the estimated error. Of the three exhaust emissions being considered, the carbon monoxide measurement is most sensitive to the variables studied. This would be expected since both the within and between vehicle variances for CO are larger relative to the measured mean than those for HC and NO.

It is somewhat surprising that the various temperature conditioning options shown in Figures 5-1 through 5-3 had so small an effect on the estimated population variance. However, review of component error sources reveals that the errors resulting from correcting emission measurements for the effect of initial engine block temperature, Table 5-3, are small relative to the between and within car variability and, further, that they are not greatly different for the individual temperature conditioning options studied.

TABLE 5-3

ERRORS RESULTING FROM CORRECTING EMISSIONS MEASURED WITH
THREE TEMPERATURE CONDITIONING OPTIONS TO THOSE WHICH
WOULD HAVE BEEN DETERMINED WITH A FEDERAL TEST

<u>Procedure</u>	<u>Standard Error</u>		
	<u>HC</u> ppm	<u>CO</u> %	<u>NO_x</u> ppm
Hot Starts (equivalent to 200°F block water temp)	14	0.16	149
Block water temperature conditioning to 200°F	24	0.13	180
Block water temperature conditioning to 100°F	3.6	0.02	24

FIGURE 5-1

SENSITIVITY OF HC STANDARD ERROR
TO MEASUREMENT PROCEDURES
95% CONFIDENCE LEVEL

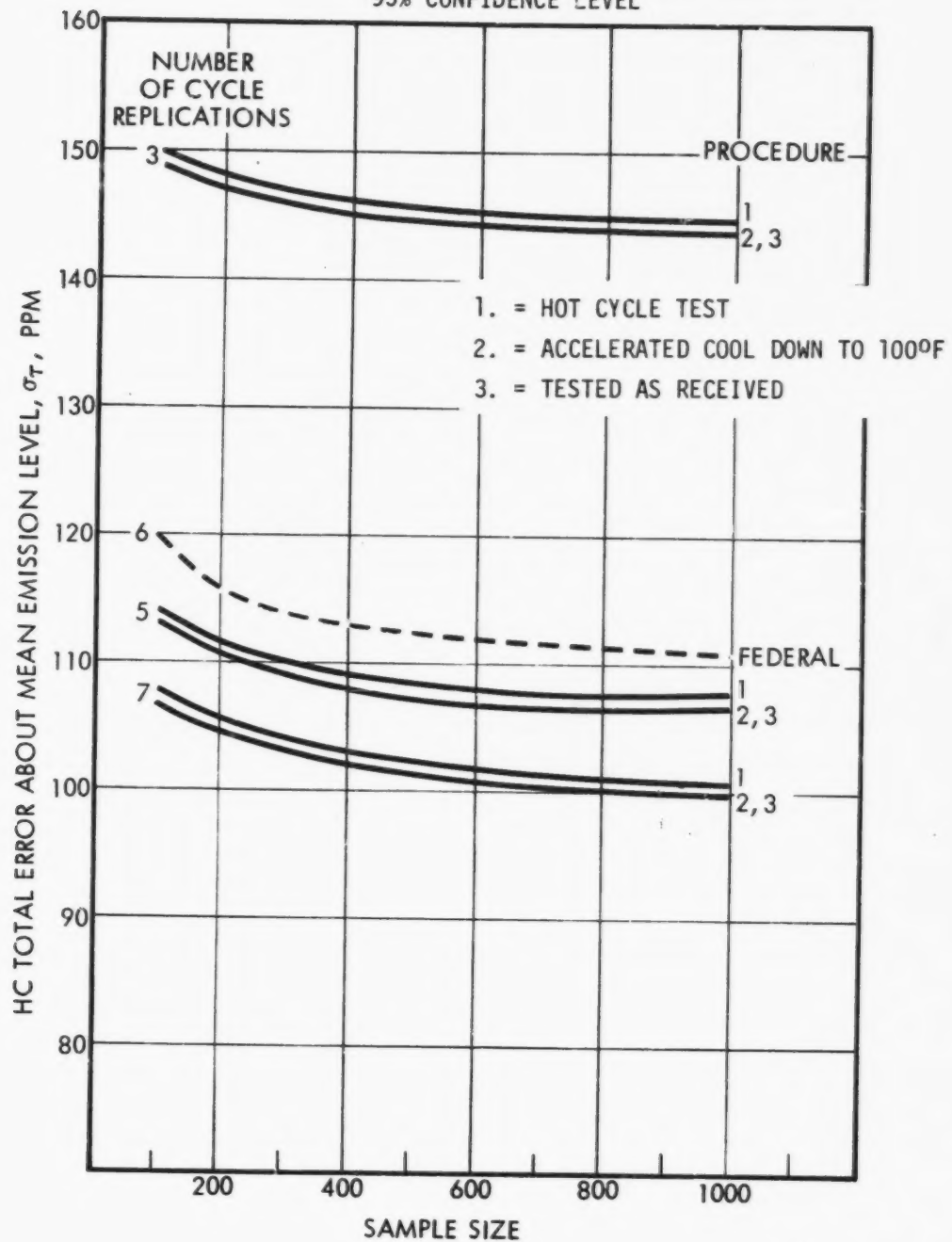


FIGURE 5-2

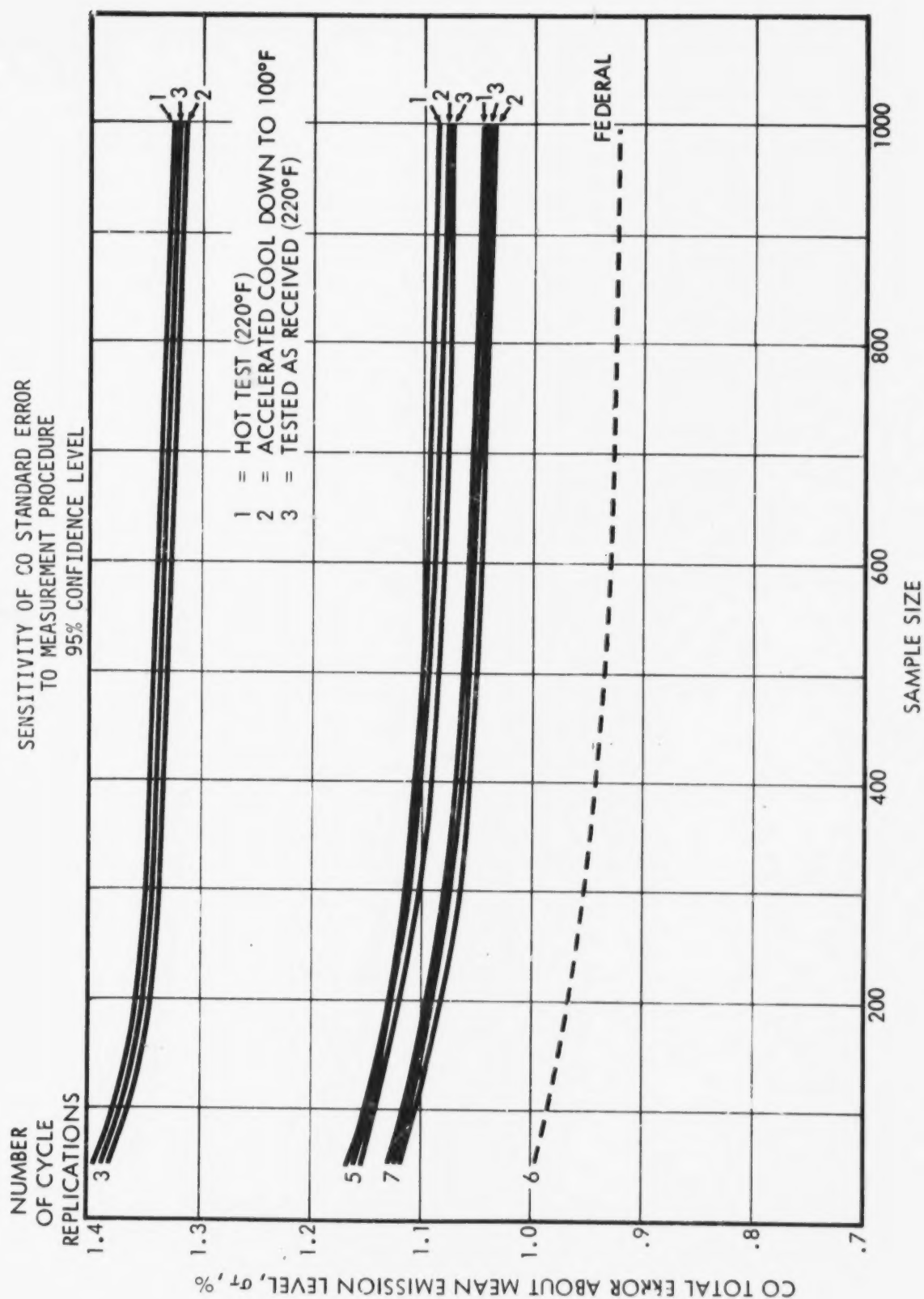
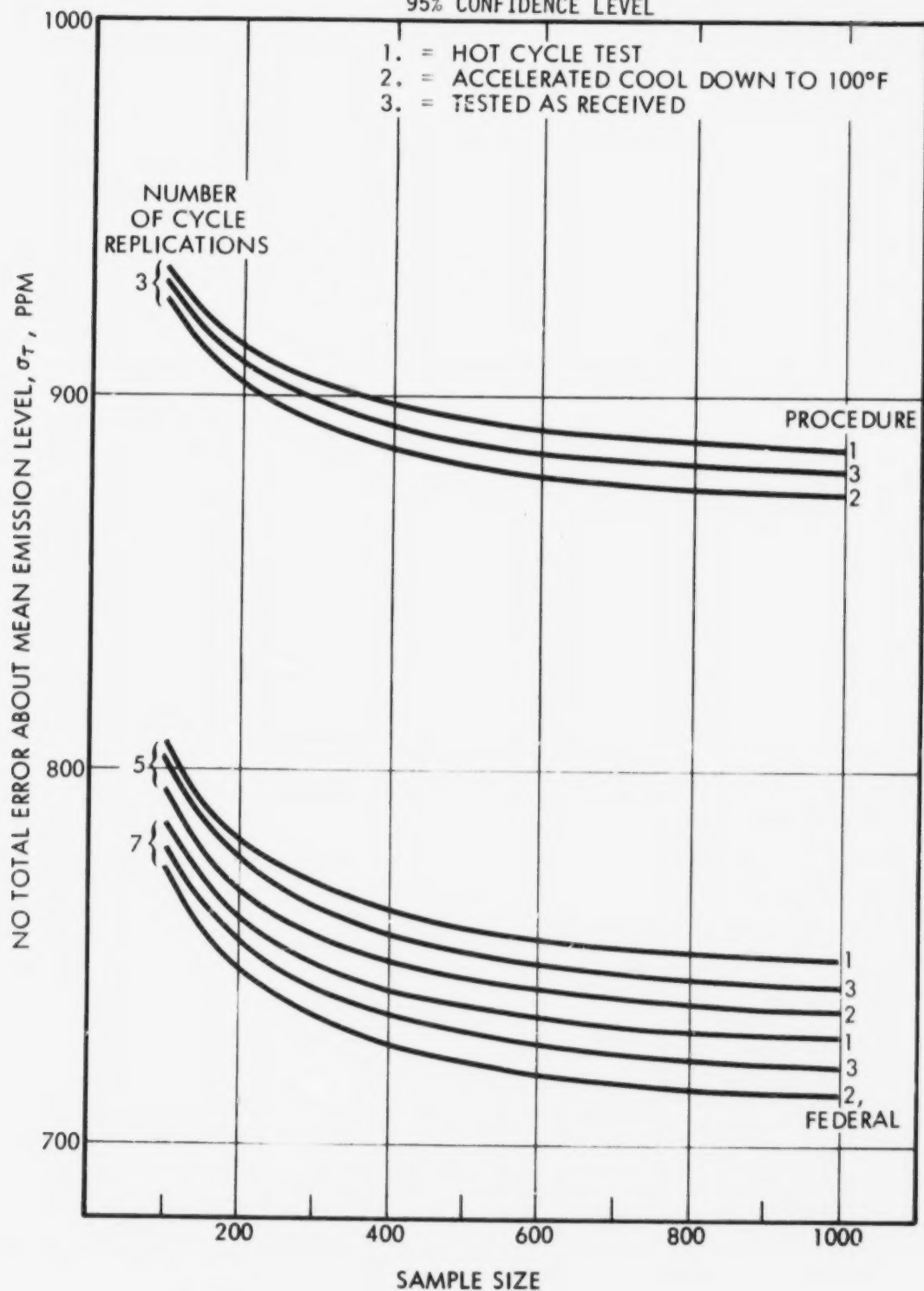


FIGURE 5-3

SENSITIVITY OF NO STANDARD ERROR TO
MEASUREMENT PROCEDURE
95% CONFIDENCE LEVEL



Figures 5-4 and 5-5 show the estimated errors introduced in correcting HC and CO emissions measured at various initial block water temperatures to those which would have been determined using the Federal procedure.

Table 5-3 shows that the error involved in making the temperature bias correction, hot-cycle to equivalent cold start test, is approximately equal to those predicted from the temperature conditioning test data for an initial block water temperature of 200°F. This indicates reasonable consistency between the data sets as well as in the modeling approach used in this analysis. A further indication of internal data and modeling consistency is obtained from Figures 5-1 through 5-3 by comparing the estimate of standard errors for the full Federal test procedure with those of replicated tests using the other temperature conditioning options. Since the full Federal procedure is essentially a six-cycle test (the fifth cycle of the seven runs is not read), the emission measurement errors for the Federal procedure would be expected to fall between those determined for five and seven cycle replications. The estimated standard error of HC emissions measurements using the Federal test procedure is seen to fall between the errors estimated for three and five replications of the 7-mode cycle while the estimated standard error of Federal test CO measurement is less than that predicted for seven-cycle replications. The NO standard error from the Federal test lies essentially on the measurement procedure which conditions the engine block to 100°F and uses seven replicated cycles. This indicates some inconsistency in the model which doubtlessly has resulted from using a number of different data sets and approximations. However, a hypothesis test that the population variances of emission measurements made with the Federal procedure are different than these made with five or seven replications of the seven-mode cycle cannot be confirmed with a reasonable level of significance using an "F" ratio test.

It is evident from this discussion that the selection of optimum procedures must be based largely upon cost considerations since the various procedural options for identical numbers of cycle replications and sample sizes yield similar population variances for mean atmospheric emissions. When considering cost it is important to note that using

FIGURE 5-4

SENSITIVITY OF HC TEMPERATURE CONDITIONING BIAS
CORRECTION ERROR TO BLOCK TEMPERATURE

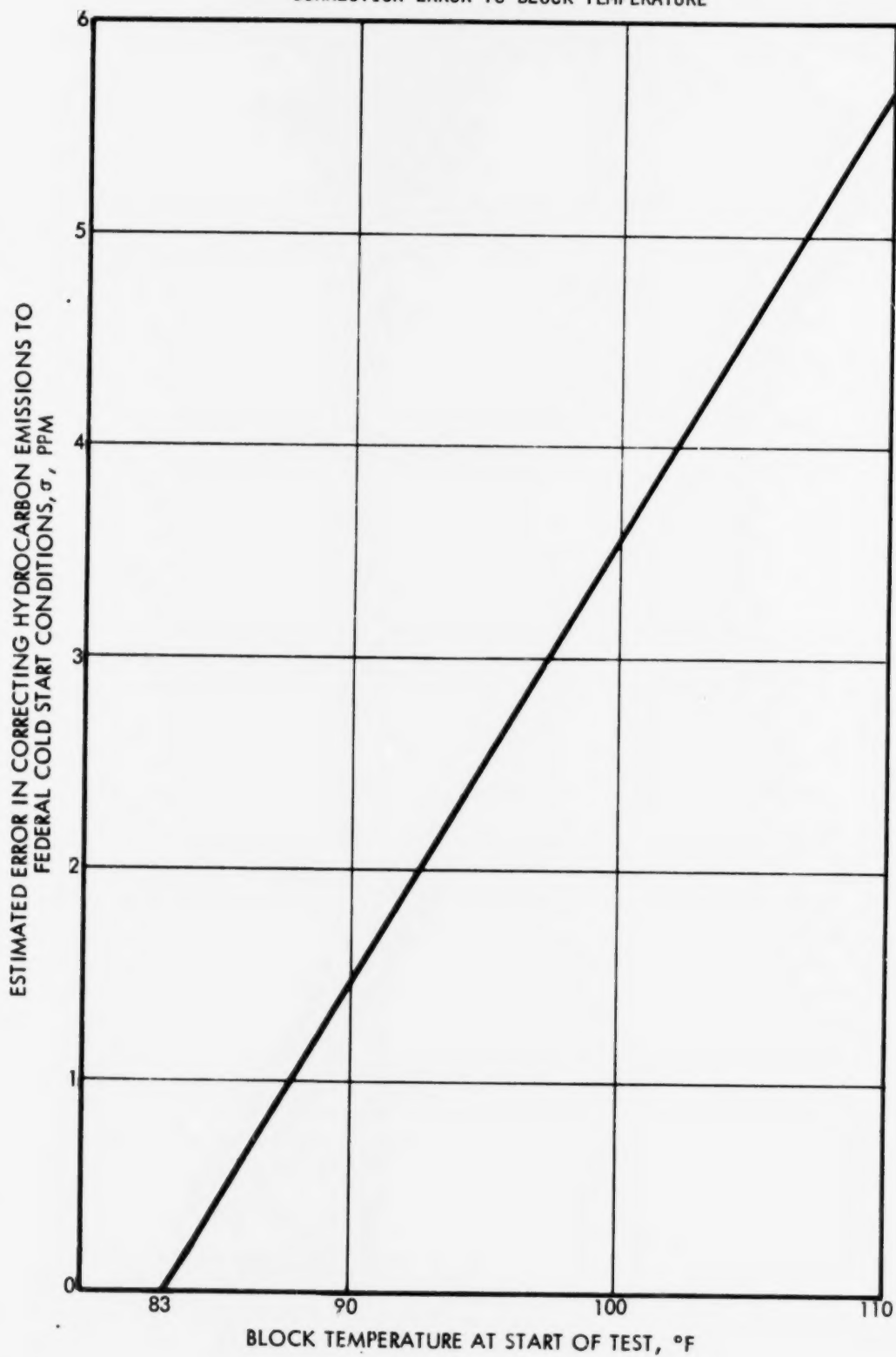
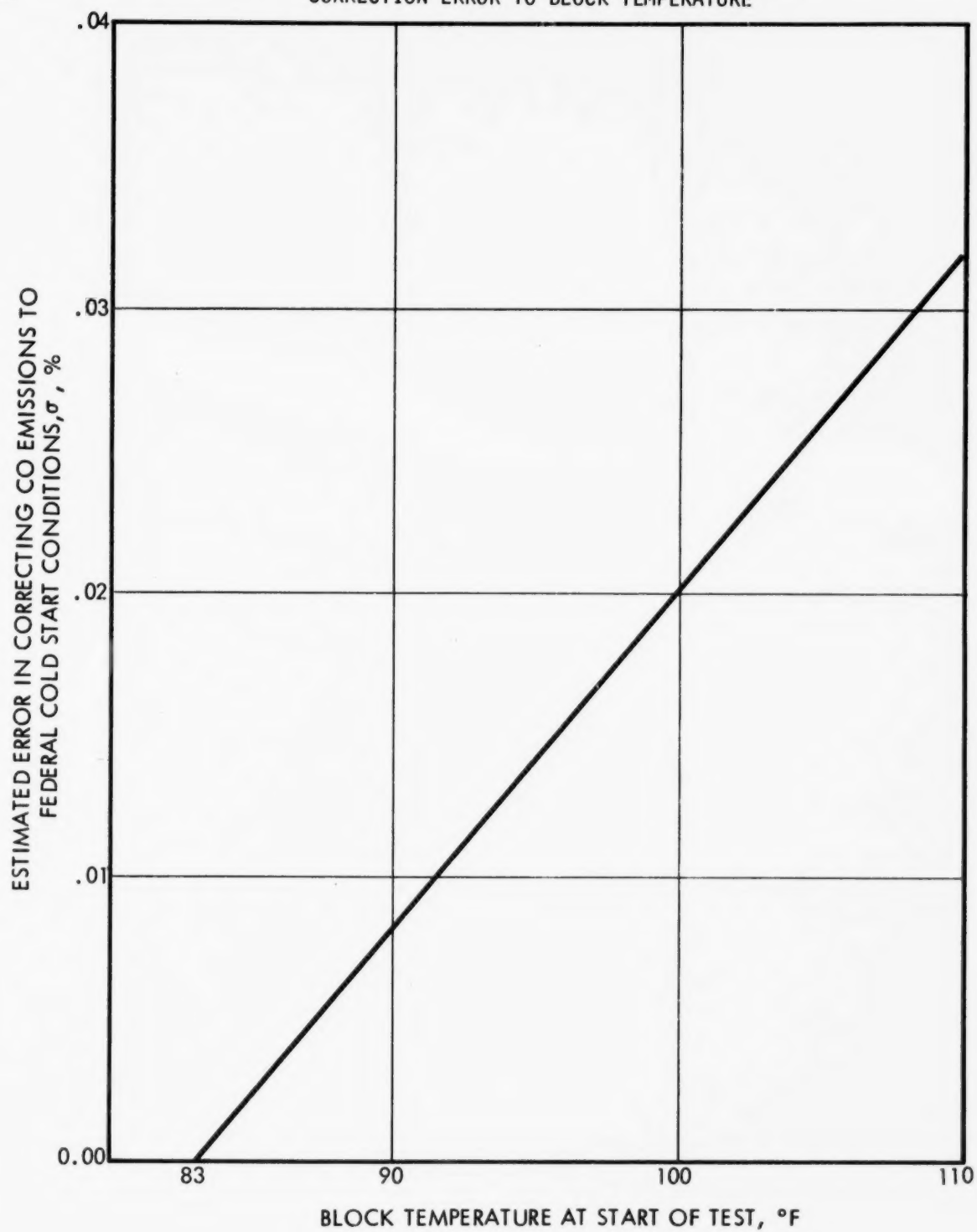


FIGURE 5-5

SENSITIVITY OF CO TEMPERATURE CONDITIONING BIAS
CORRECTION ERROR TO BLOCK TEMPERATURE



temperature conditioning options other than that of the full Federal procedure requires development of empirical factors for correcting temperature bias. For hot-start tests (option one), between 100 and 200 vehicle tests are required to obtain a stabilized estimate of the composite to hot cycle correction factor (bias and precision errors). The temperature conditioning development work performed during this program which has been used as a basis for developing the correction factors required approximately 99 vehicle tests (11 power trains x 9 tests). Therefore, a fixed cost for conducting 100 Federal tests was assessed against surveillance programs which involved using temperature conditioning procedures different than that specified for a Federal emissions test. Of course, when the surveillance program involves testing using replicated hot cycles, the two hot cycles of these Federal tests can be combined with the surveillance program tests to form the data base. The above considerations are reflected in the total and per test cost estimates presented below.

The total program costs and the cost per vehicle for surveillance performed using mobile stations in industrial parking lots with various temperature conditioning options are presented in Figures 5-6 and 5-7. A number of conclusions are readily apparent:

- For a surveillance program in which the required prediction confidence allows using a relatively small number of vehicles (75-200) very little cost saving can be effected using a temperature conditioning option other than that specified in the Federal procedure because of the large fixed cost to develop the emissions correction factors.
- The cost differential of replicating cycles is small compared to other costs (approximately \$1/cycle).
- Unit costs per vehicle tend to fall into two groups reflecting those procedures requiring cooling down vehicle power trains before testing and those involving running either hot cycles or the car in its "as-received" condition.

The cost impact of starting the emissions tests at different power train temperatures following the application of one of the accelerated cool-down procedures is shown in Figure 5-8 for a sample size of 400 vehicles. As would be expected from the nature of the power train temperature response curves, Figures 3-12 and 3-13, the cost differential between the two basic

FIGURE 5-6

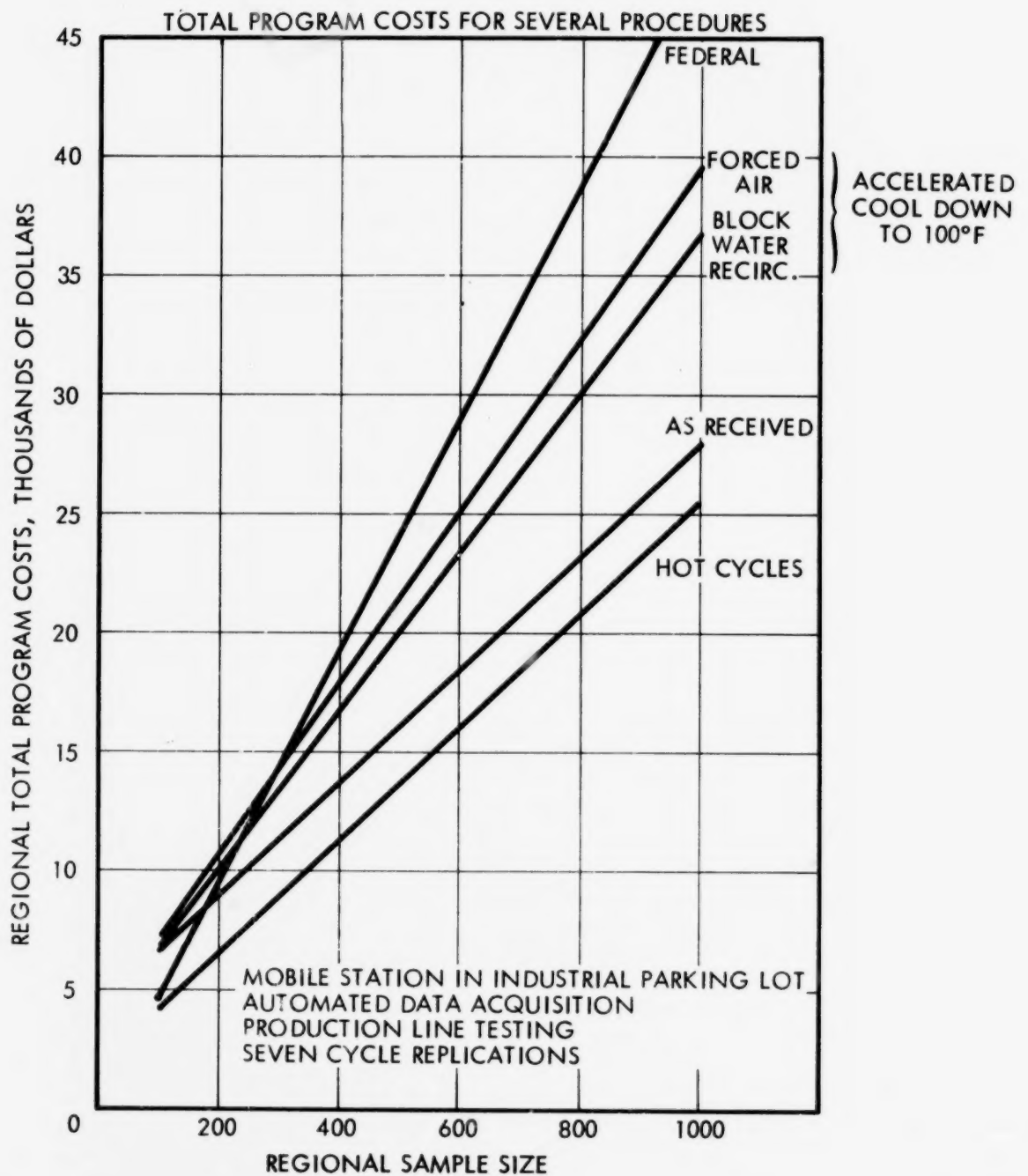


FIGURE 5-7
COST PER VEHICLE TEST FOR SEVERAL PROCEDURES

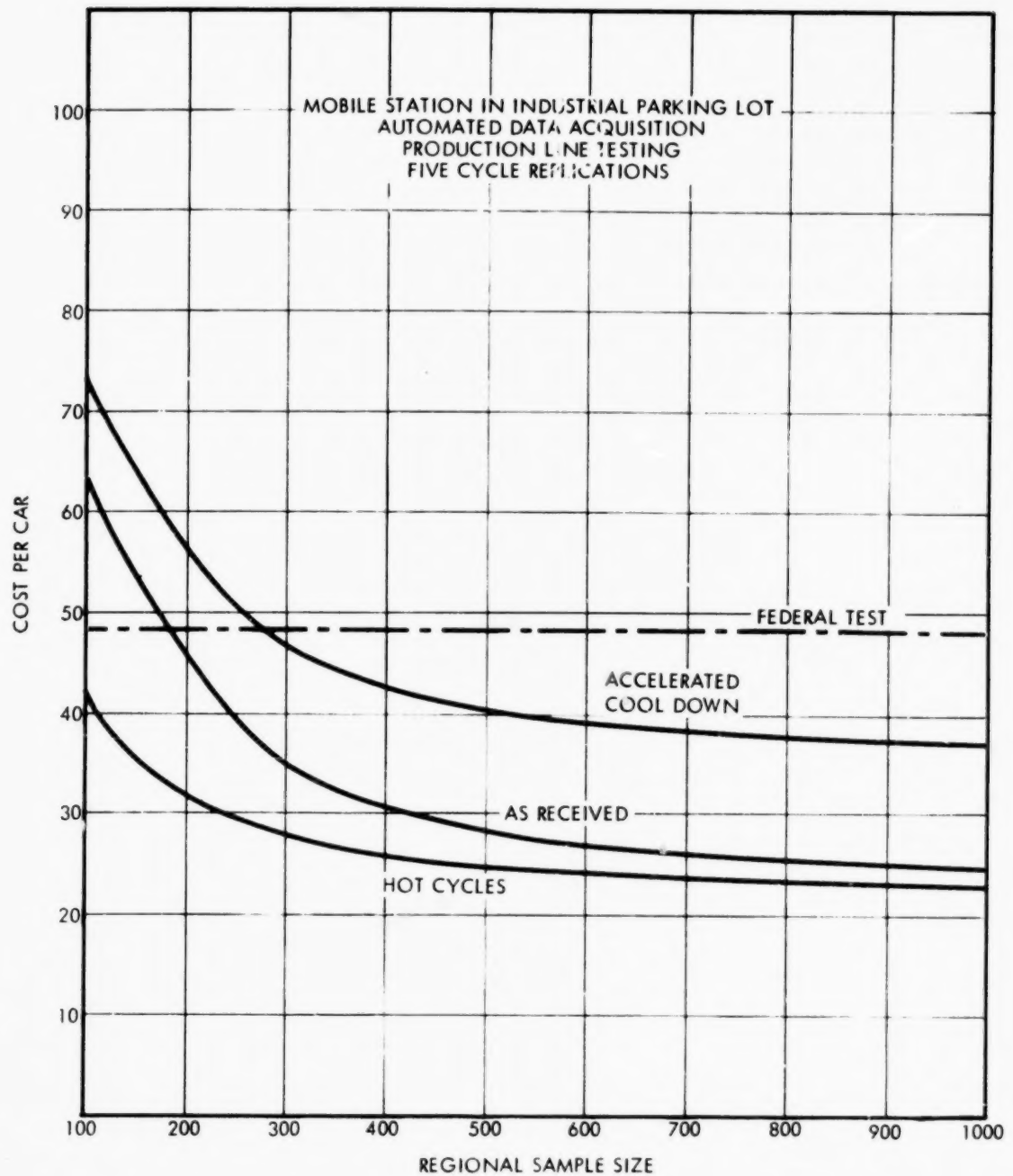
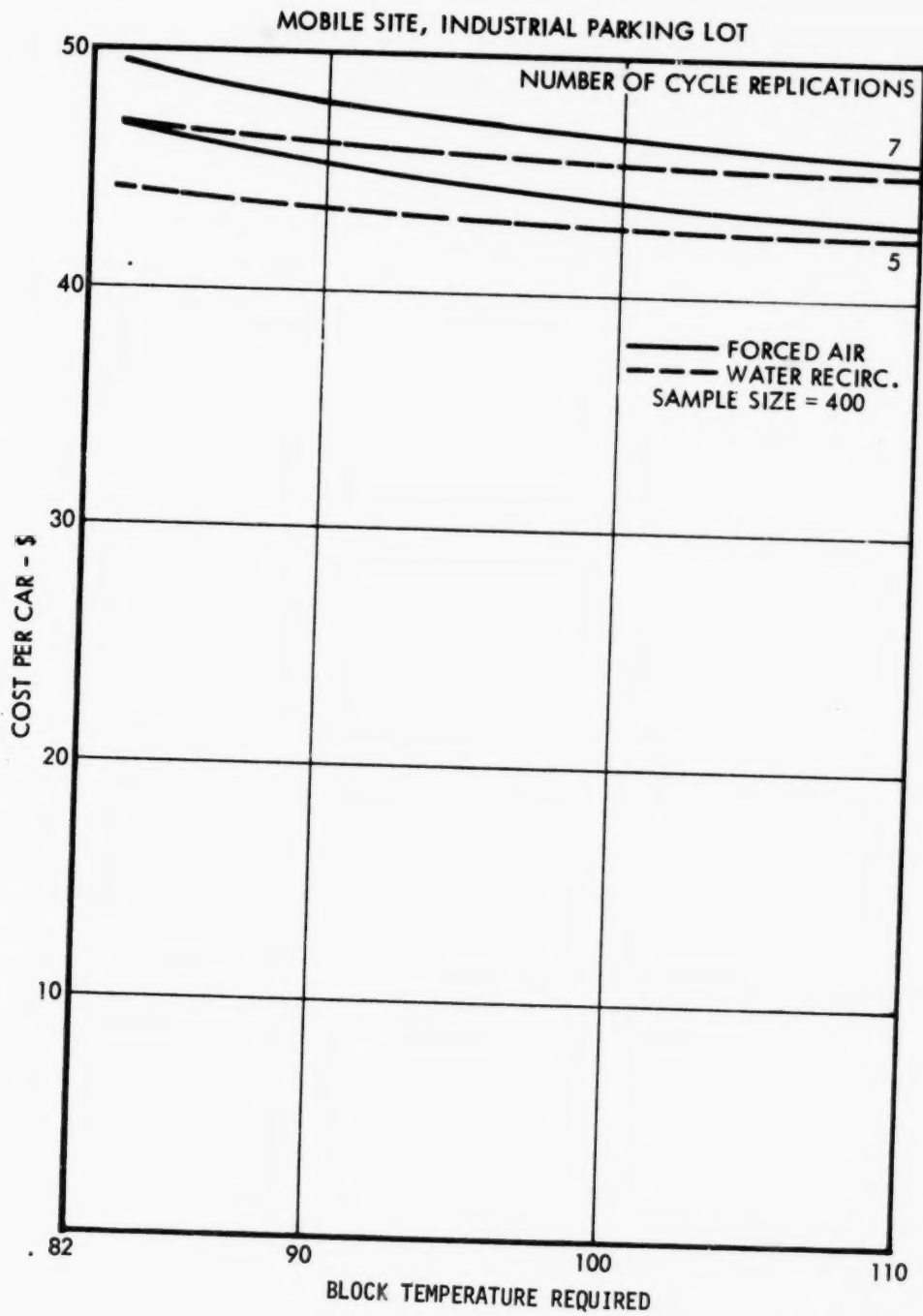


FIGURE 5-8

COST SENSITIVITY TO TEST TEMPERATURE
FOR ACCELERATED COOLING PROCEDURES



accelerated cool-down procedures becomes small as higher block water temperatures are used at the start of testing, i.e., as shorter temperature conditioning periods are selected. Because the accelerated cool-down procedure which uses only forced air is the simplest to implement, it is the favored procedure under these conditions. If an initial power train test temperature near ambient is required then the accelerated cool-down procedure using cooling water circulation is less costly by about \$2.50 per vehicle.

If a surveillance program is to be conducted to make comparisons between regions and if it can be assumed that the emission test correction factors are invariant between regions, then the tests required to develop these correction factors can be performed once and their cost amortized over the entire program. Unit costs in this case would be near those of testing a large number of cars in a single region and can be estimated from Figure 5-7 for a 1000 car sample. Unit costs are found to range between 23 and 48 dollars per car as the temperature conditioning procedures are varied from a stabilized hot start to that specified by the Federal test procedure. Analysis of the EPA data, however, indicates that a regional difference in hot cycle to composite emission correction factors did exist. Therefore, it must be assumed that separate correction factors would have to be developed for each region at least until further experimental evidence is accumulated to prove that regional bias effects can be ignored.

The size of the temperature correction factors and, hence, the importance of regional bias becomes small as accelerated cool-down procedures are used to produce engine temperature states near those of the Federal procedure. Penalizing the accelerated cool-down procedures in this instance for the cost of 100 Federal tests is probably not entirely justified. For these cases, significantly fewer than 100 Federal tests would probably have to be performed to substantiate the fact that no significant difference existed between emissions measured using accelerated cool-down procedure and the full Federal procedure. In this case the cost of the 100 Federal tests certainly could realistically be prorated over a multi-regional program.

A system figure-of-merit was selected with which to perform comparisons between program strategies and temperature conditioning options. This figure of merit reflects the system cost-effectiveness and is defined as the product of the estimate of the emissions population standard error and the total system cost. A minimum of this functional is to be used to establish performance values for the various available program alternatives.

The cost-effectiveness of performing various numbers of cycle replications was first evaluated for several vehicle sample sizes and temperature conditioning options. These results are shown in Figures 5-9 and 5-10 for HC and CO, respectively. The cost-effectiveness index also is shown for the full Federal procedure as a point of reference.

The most cost-effective number of cycle replications for measuring HC emissions lies between 5 and 6 for all combinations of temperature conditioning options and sample sizes. The optimum point tends to move toward fewer replicated cycles as the value of the cost effectiveness index (primarily cost) increases, Figure 5-9. Similar results were obtained for CO, Figure 5-10.

Figures 5-11, 5-12 and 5-13 indicate that the Federal procedure is the most cost effective for a surveillance program involving approximately 100 vehicles. As the test sample size increases and the costs of establishing temperature correction factors are spread over a larger number of tests, the shorter test procedures become more cost effective. Those procedures which fall below the Federal procedure figure of merit are the most economic-effective. For example, for sample sizes over 400 vehicles the hot-cycle procedure is approximately 50% more cost-effective than the Federal based on predicting CO emissions, Figure 5-12.

It is noted that costs associated with establishing hot start to Federal test emissions correction factors can be avoided by changing the Federal test procedure to correspond to one of the "shorter" tests. There are, of course, attendant disadvantages.

Figures 5-14 and 5-15 show the cost effectiveness of the two accelerated cool-down procedures as the temperature at the beginning of emission testing is allowed to vary. Again the sensitivity of cost-effectiveness to this variation is small because the impact of initial power train

FIGURE 5-10

SENSITIVITY OF SYSTEM FIGURE OF MERIT BASED
ON CO TOTAL ERROR TO PROCEDURES

MOBILE SITE, INDUSTRIAL PARKING LOT

- 1 = HOT CYCLES
- 2 = ACCELERATED COOL DOWN
- 3 = AS RECEIVED

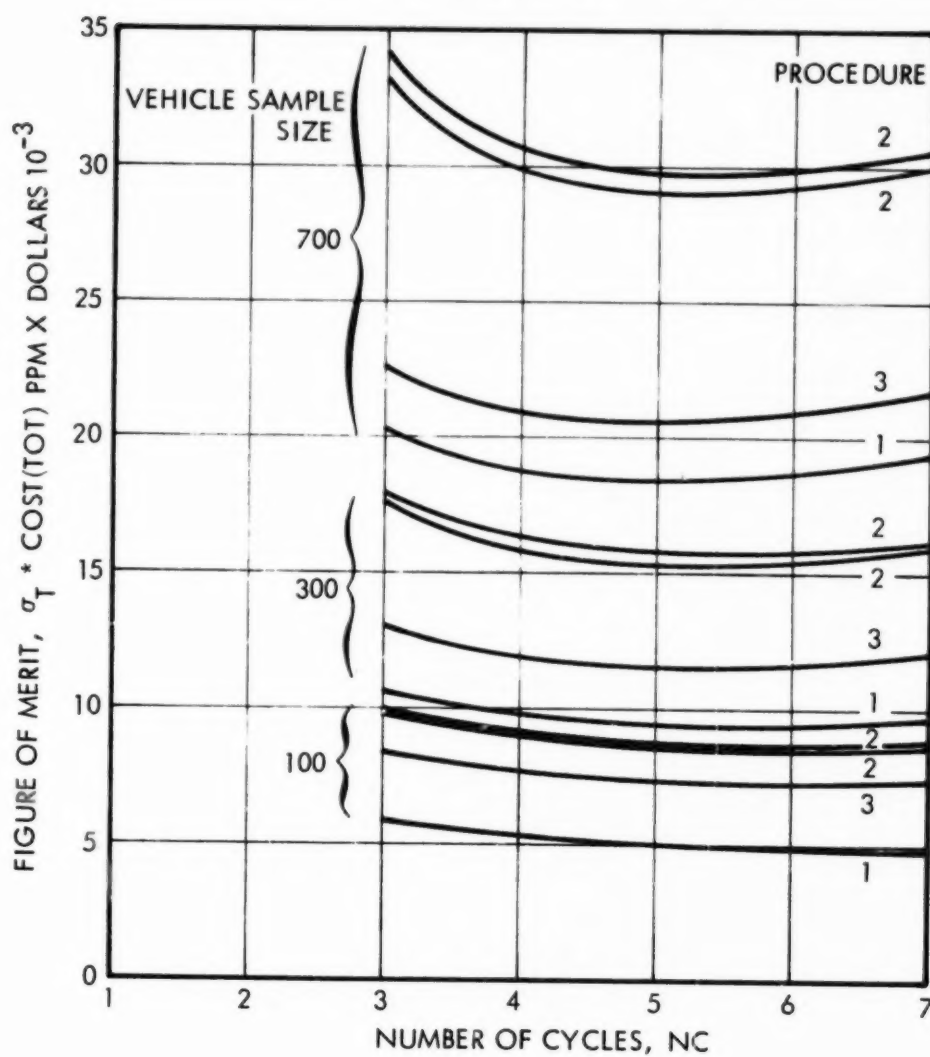


FIGURE 5-11

SENSITIVITY OF SYSTEM FIGURE OF MERIT BASED
ON HC TO SAMPLE SIZE

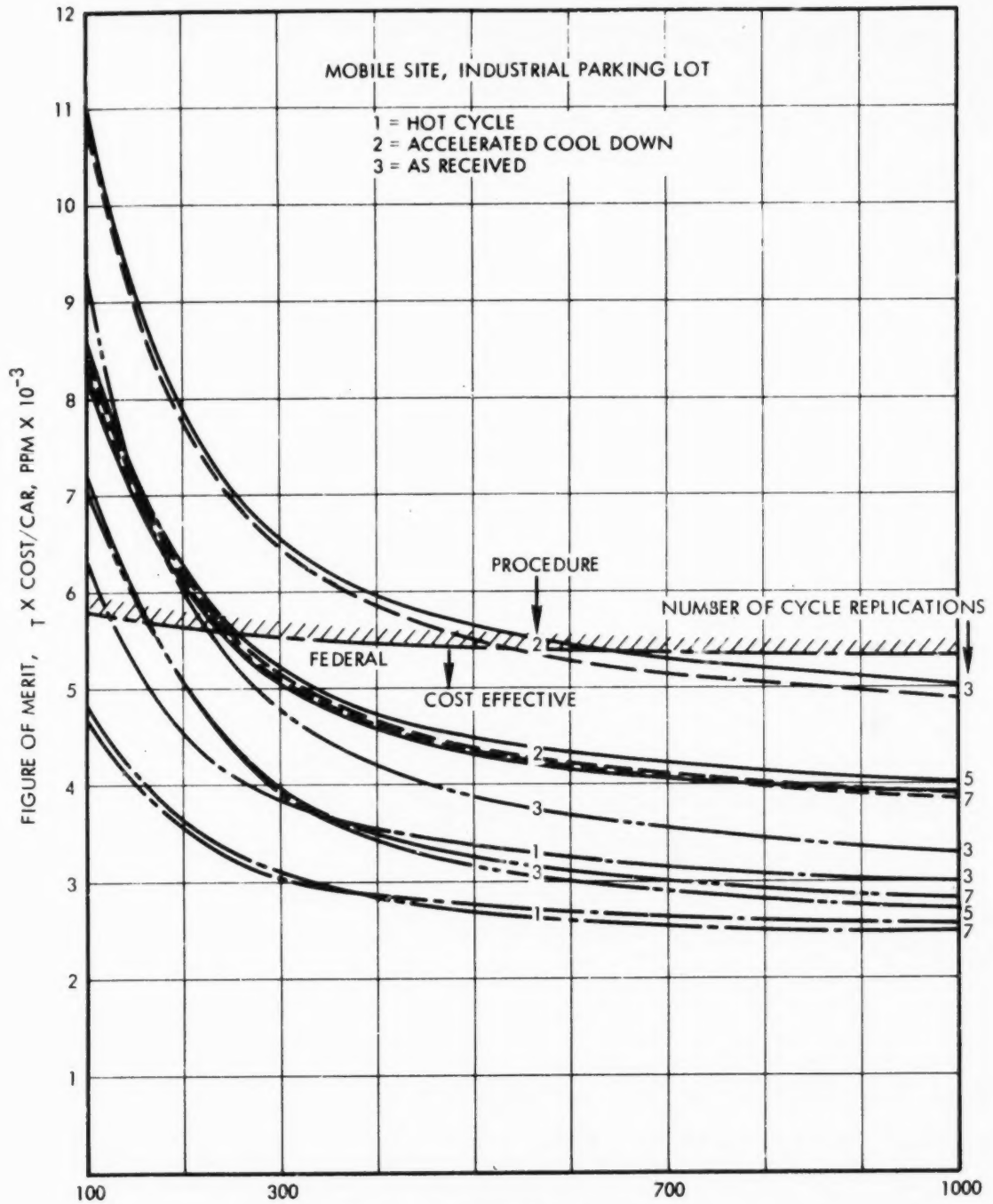


FIGURE 5-12

SENSITIVITY OF SYSTEM FIGURE OF MERIT BASED
ON CO TO SAMPLE SIZE

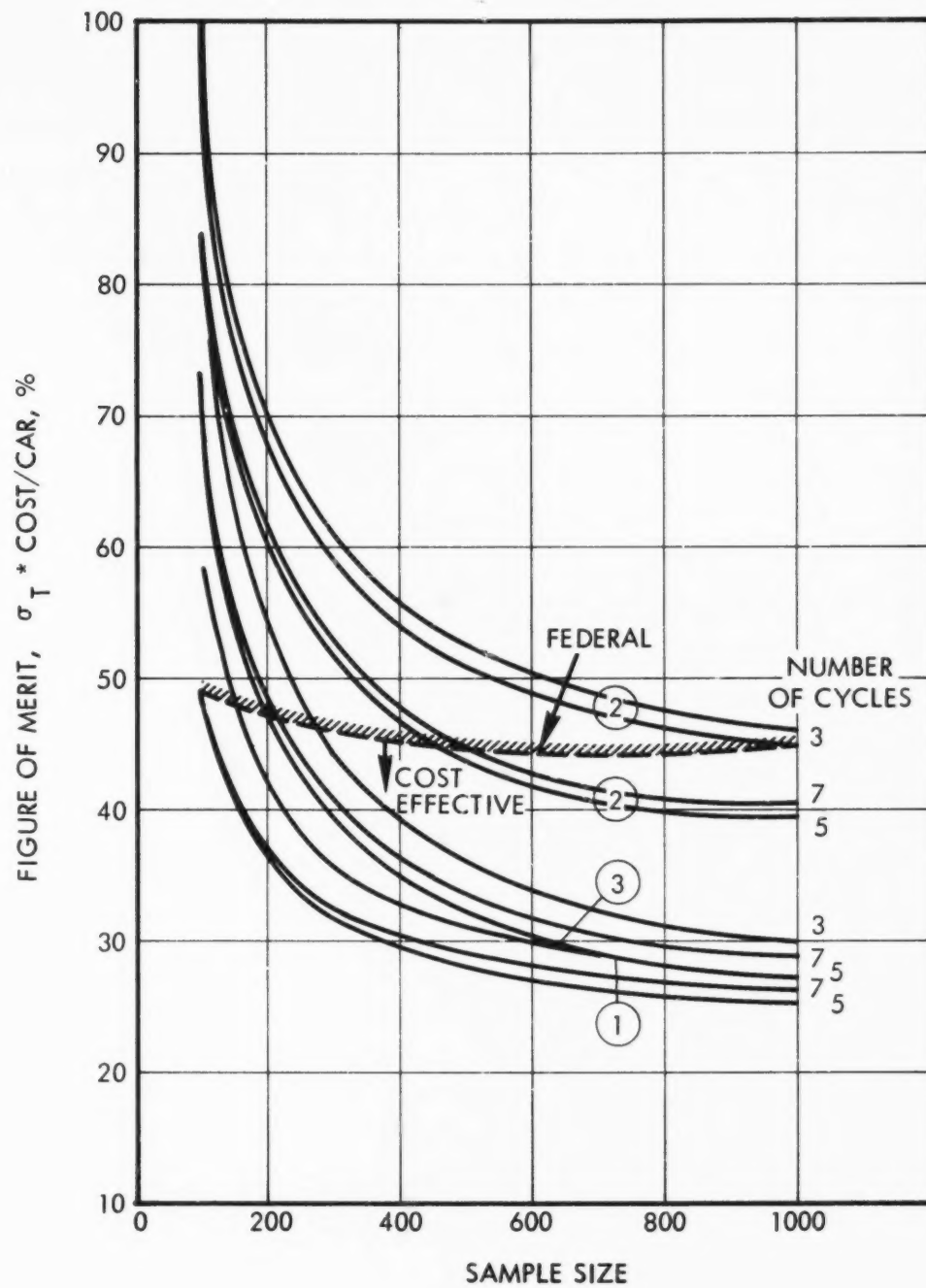


FIGURE 5-13

SENSITIVITY OF SYSTEM FIGURE OF MERIT BASED
ON NO TO SAMPLE SIZE

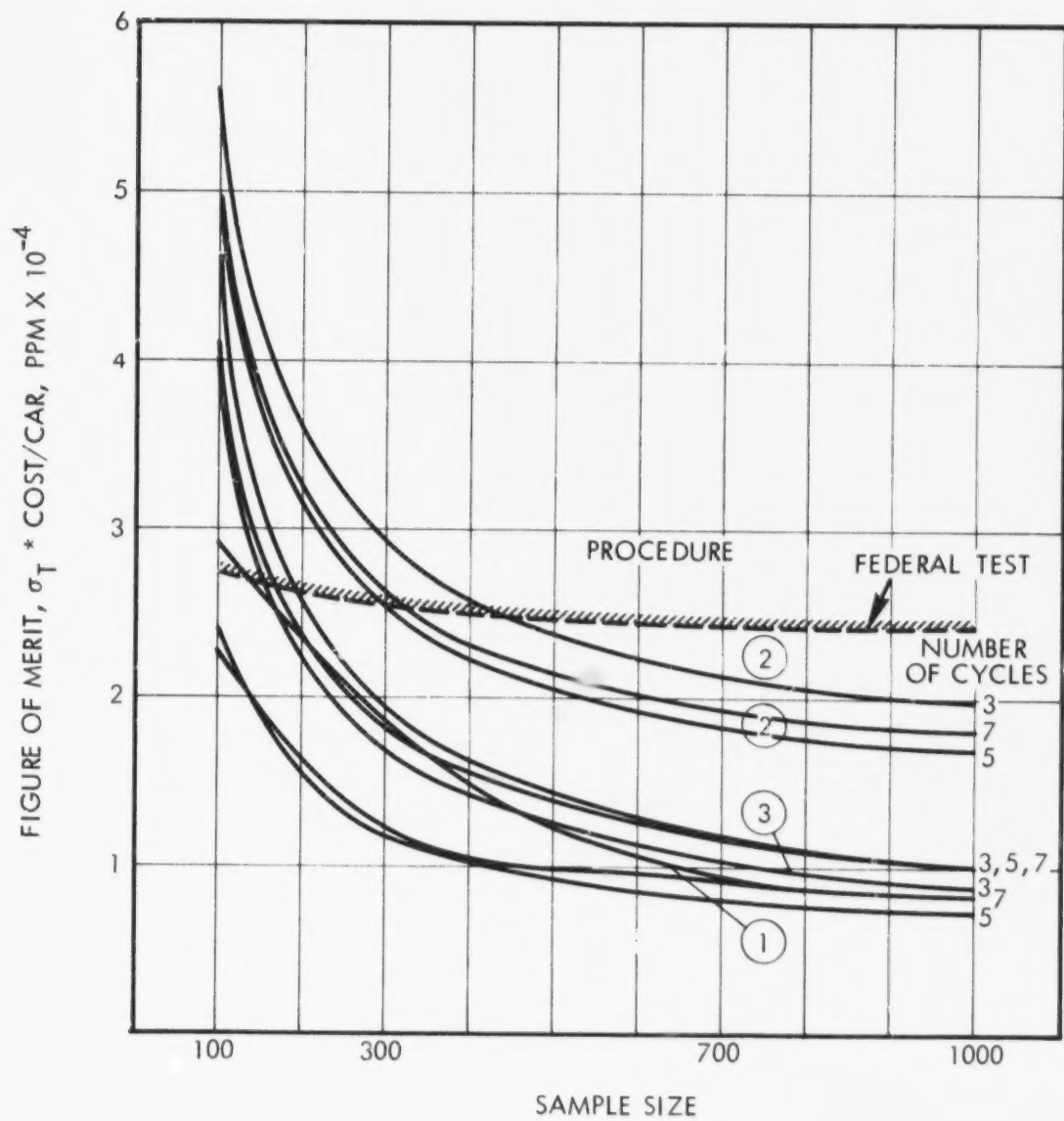


FIGURE 5-14
SENSITIVITY OF FIGURE OF MERIT BASED ON HC
TO ACCELERATED COOL-DOWN

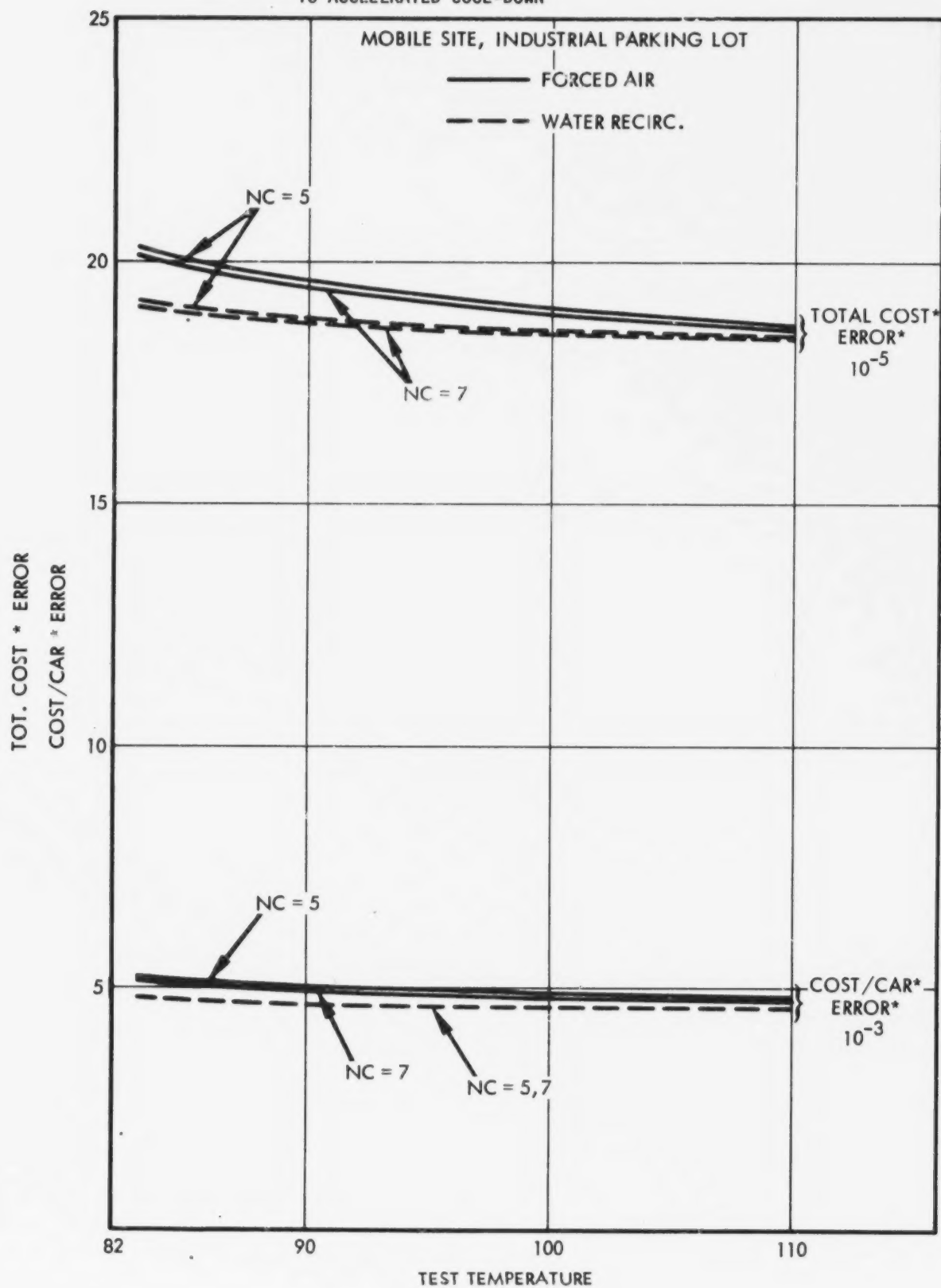
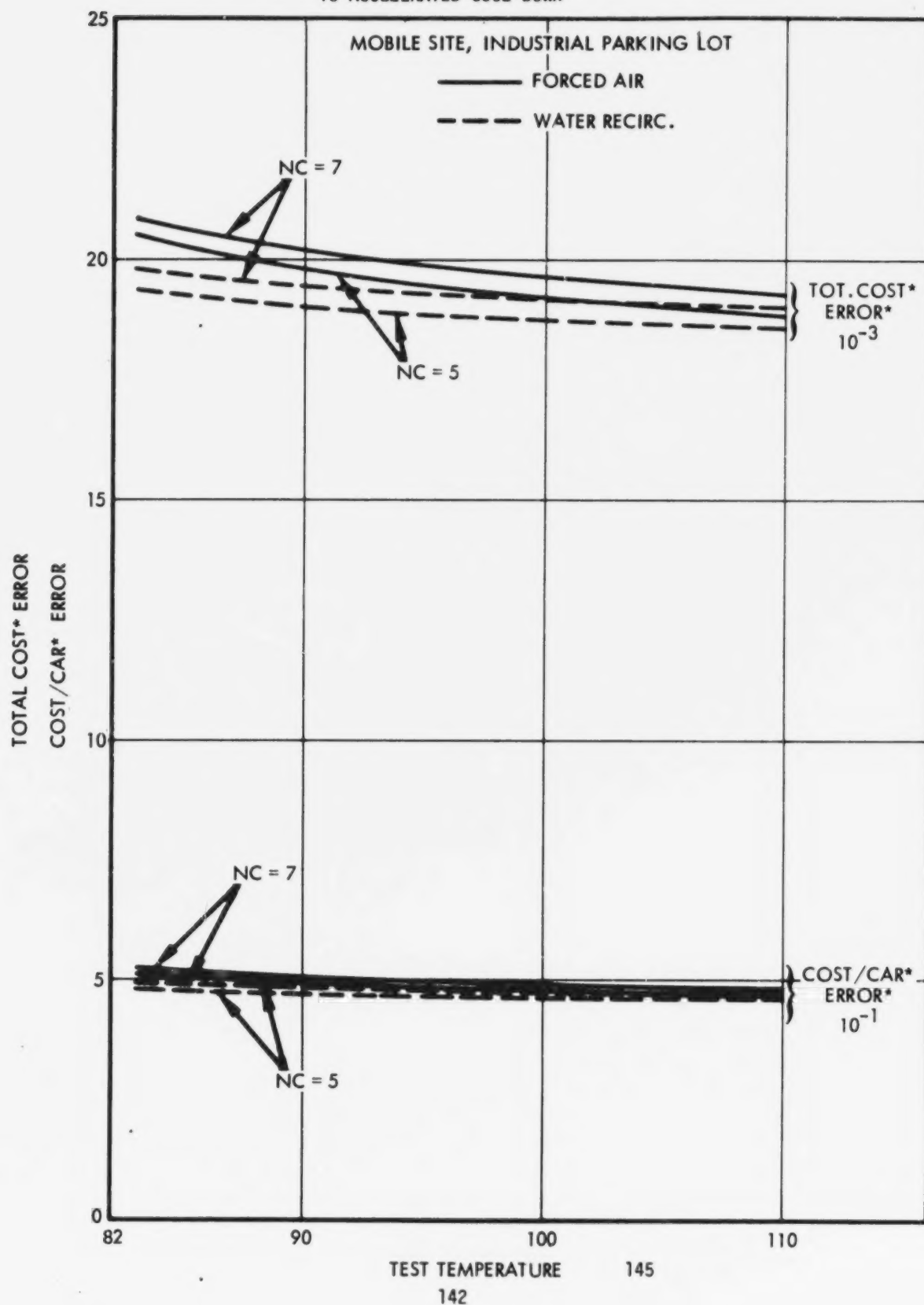


FIGURE 5-15
SENSITIVITY OF FIGURE OF MERIT BASED ON CO
TO ACCELERATED COOL-DOWN



temperature upon total error is small. Clearly, testing at higher power train temperatures is cost-effective when forced cool-down is employed.

The following observations are made based upon the cost effectiveness studies:

- There is little difference in the cost-effectiveness of the two accelerated block water temperature cooling procedures.
- There is a significant difference in the cost-effectiveness of the two methods for performing hot-start tests. Testing in the "as-received" condition is always less cost-effective than testing with a stabilized hot-start condition.
- The break even point for a five-cycle test to measure HC emissions relative to performing a full Federal test occurs between 90 and 135 vehicles for hot testing and between 165 and 175 vehicles for tests involving accelerated cool-down. Similar values for CO are 90 to 200 and 450 to 475 vehicles, respectively.

Table 5-4 shows the cost-effectiveness of a four region surveillance program using several different test procedures. These data are based upon testing 300 vehicles in the four most highly populated regions of the United States. The regions chosen were the California-Oregon region, the Great Plains Region, the Great Lakes Region and the Northeastern Region. Cost-effectiveness indices are shown for both HC and CO. Where the test procedures require the development of corrections factors to relate test emissions to those which would have been determined by a Federal test, both the cost and error impact of the required Federal tests are estimated. Stabilized hot-cycle testing results in the largest estimated measurement error, but is most cost-effective. Testing vehicles in their "as received" temperature states also appears to be cost-effective.

A very large cost difference is incurred when full Federal tests are run for surveillance. The attendant estimate of standard error, of course, is lower than with other test procedures, but the range between the estimated standard errors for CO measurements across all procedures considered is only from 0.95 to 1.10 percent. The forced air accelerated cool-down procedure appears as a poor compromise between the Federal test and hot-cycle testing. The forced air procedure is approximately 15% more cost-effective while hot-cycle tests are 30 to 50% more cost-effective, depending on whether or not correlations must be established for each region.

TABLE 5-4

TOTAL COSTS OF A FOUR-REGION SURVEILLANCE PROGRAM
USING 300 VEHICLES PER REGION(Emissions Error Estimated at 95% Confidence Level, Mobile Station
Used in Truncated Procedures)

Element	Federal	Hot ¹ Cycle	Hot ² Cycle	Forced ^{1,3} Air	As Re- ceived ¹ 9500	As Re- ceived ² 9500
Cost of 1st Region	1400	8500	8500	13500	9500	9500
Cost of 2nd to 4th	43000	16700	25500	30600	19800	28500
Total Cost, \$	57000	25200	34000	44100	29300	38000
Estimate of σ_T^4 CO, %	0.95	1.10	1.10	1.05	1.07	1.07
Figure of Merit $\sigma_{TCO} * \$'s * 10^{-4}$	5.42	2.77	3.74	4.62	3.41	4.07

- 1 - Correlation to Federal procedure established in single region
 2 - Correlation to Federal procedure established in each region
 3 - Block conditioned to 1000F
 4 - Based on five cycle replications

5.2 Cost Impact of Fixed Versus Mobile Test Sites

The previous discussion has been based upon the base line case involving surveillance testing in a mobile test facility located on industrial parking lots. The cost of operating a fixed test facility as opposed to a mobile test station is presented in Figure 5-16 for two alternative methods of power train temperature conditioning. Additional costs associated with using a fixed test site are primarily caused by two cost factors:

- Operating costs or owner inconvenience costs associated with transporting the vehicle to the fixed test location
- Investment costs in land area for storing and testing vehicles.

The incremental operating costs were calculated assuming an average 30-mile round trip to the test location driven at an average speed of 22 mph. An owner inconvenience cost of \$2/hour and a vehicle transport cost of \$0.10/mile were assumed. The additional costs of operating a fixed test site over a self-propelled mobile station were determined to be \$5 and \$4 per vehicle for facilities using accelerated cooling and warm-up, respectively. The slightly larger costs for using accelerated cooling result from the higher investment costs to provide the larger site required for temperature conditioning the test vehicles. It should be noted that costs for the mobile test site used in the above evaluation were based on a self-propelled van costing \$25,000. A basic trailer could be purchased for \$15,000. The annular amortized cost differential for these two mobile configurations is approximately \$0.40/vehicle tested and is a relatively unimportant cost effect.

5.3 Effect of Confidence Limits

The results presented in previous sections are all based upon requiring a confidence limit of 95% when estimating the population standard error. The effects upon the program of specifying other confidence levels will be investigated briefly in this section. Based upon the estimated population standard errors, the impact on a surveillance test program of two applications of the emissions data will be investigated:

NUMBER OF CYCLES = 5
 HOT START TEMP. = 220°
 BLOCK TEMP. = 100°
 FIXED COST OF ESTABLISHING CORRELATION INCLUDED

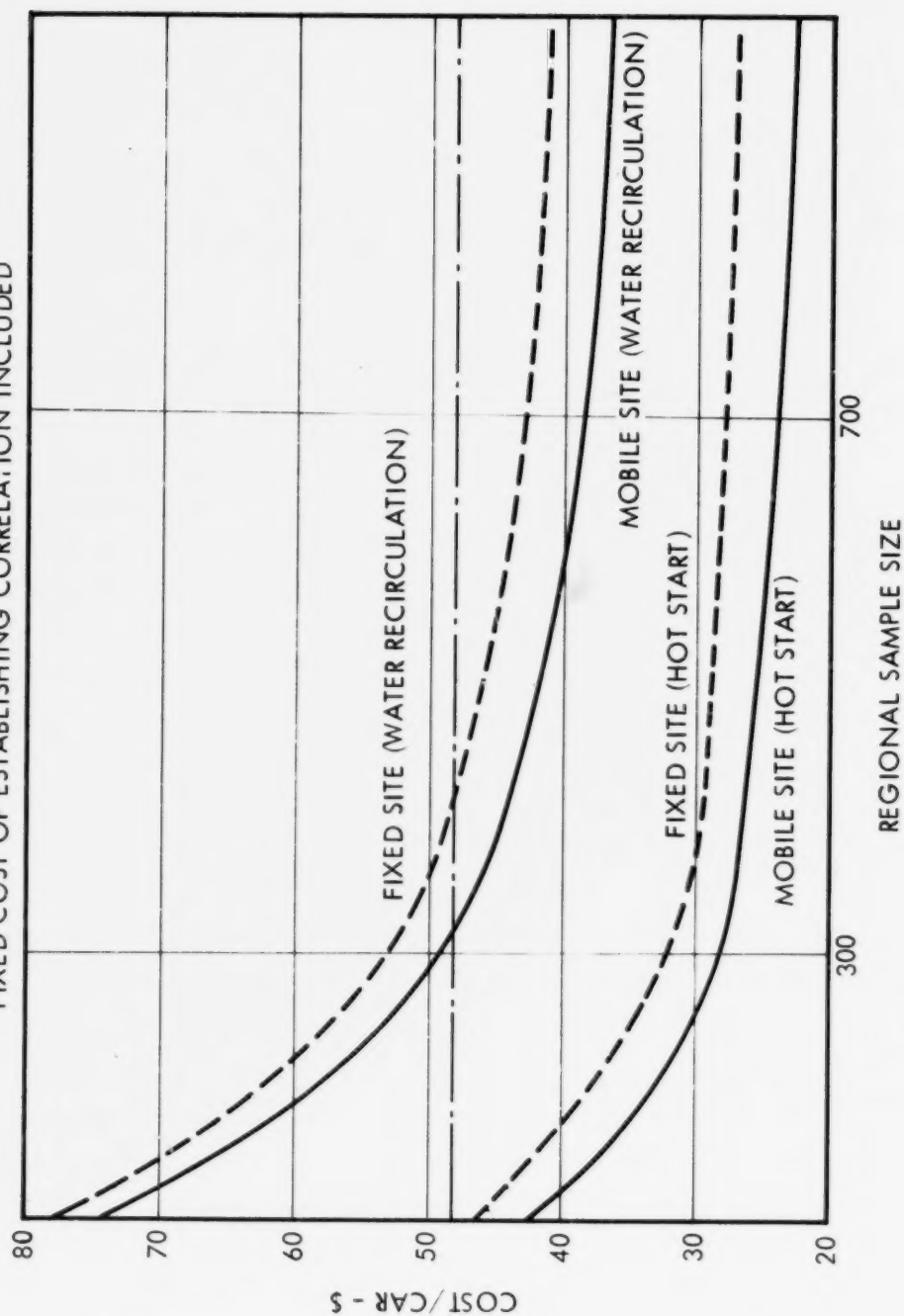


FIGURE 5-16
 COMPARISON OF FIXED AND MOBILE STATION COSTS

- Prediction of the mean emission level to the atmosphere in a single surveillance region within a specified error band and at a selected level of confidence.
- Contrasting emissions between surveillance regions within specified α and β error limits using the null hypothesis.

The effect of three confidence levels on the estimated population standard error is shown on Figures 5-17 through 5-19 for two test sample sizes and two different power train initial test temperatures. The number of test cycle replications was fixed at five for this study because this has been shown to be the most cost-effective number of replications for the range of test sample sizes thought to be consistent with the program requirements. If the required hydrocarbon standard error were to be kept to less than 110 ppm, then the sample size would have to be increased from 200 to 400 vehicles in order to improve the level of confidence in this measurement from approximately 94.8% to 95.6%. Figure 5-5 shows that the attendant program cost for the temperature conditioning option utilized would be increased from approximately \$10,000 to \$16,800. The program cost, therefore, increased 68% to produce less than a 1 percent improvement in measurement error level of confidence. Clearly, the ultimate use of surveillance data must be carefully considered and a confidence level selected which is consistent with the end use while not imposing an unnecessary cost burden on the program.

5.3.1 Confidence in Estimating Mean Emissions to the Atmosphere

Error bands about the measured emission mean values can be established for various confidence levels using a one-sided "t" test. The following equation relates the error band to the estimated mean emission level, $\bar{e}$, the population standard error, σ_T , and the sample size, n (Reference 9).

$$\text{Emissions to the atmosphere} < \bar{e} + Z_{1-\alpha} \frac{\sigma_T}{\sqrt{n}} \text{ at the } \alpha \text{ confidence level} \quad (5-1)$$

The factor $Z_{1-\alpha}$ is the normalized standard error. Values for $Z_{1-\alpha}$ were obtained from statistical tables for various confidence levels, α , and were used with previously determined values of standard error to estimate the uncertainty in predicting mean emissions to the atmosphere. Figures 5-20 and 5-21 show the relationships between the error band about the mean

FIGURE 5-17

AFFECT OF CONFIDENCE LEVEL ON ESTIMATED TOTAL
HC STANDARD ERROR OF MEASUREMENT PROCEDURE

ACCELERATED COOL DOWN
NUMBER OF CYCLES = 5
BLOCK TEMPERATURE = 110°F

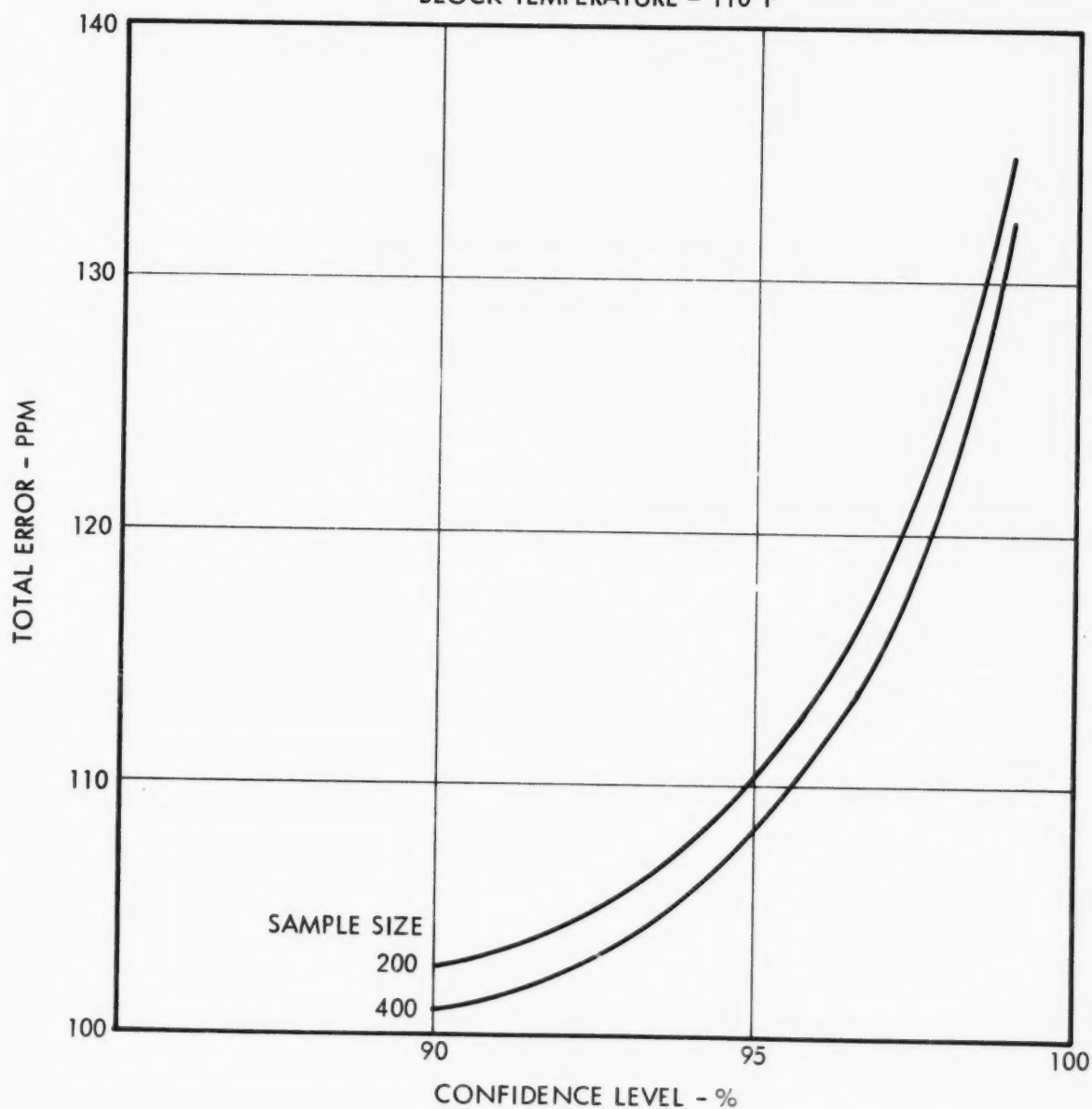


FIGURE 5-18

AFFECT OF CONFIDENCE LEVEL ON ESTIMATED TOTAL
CO STANDARD ERROR OF MEASUREMENT PROCEDURE

ACCELERATED COOL DOWN
NUMBER OF CYCLES = 5
BLOCK TEMPERATURE = 110°F

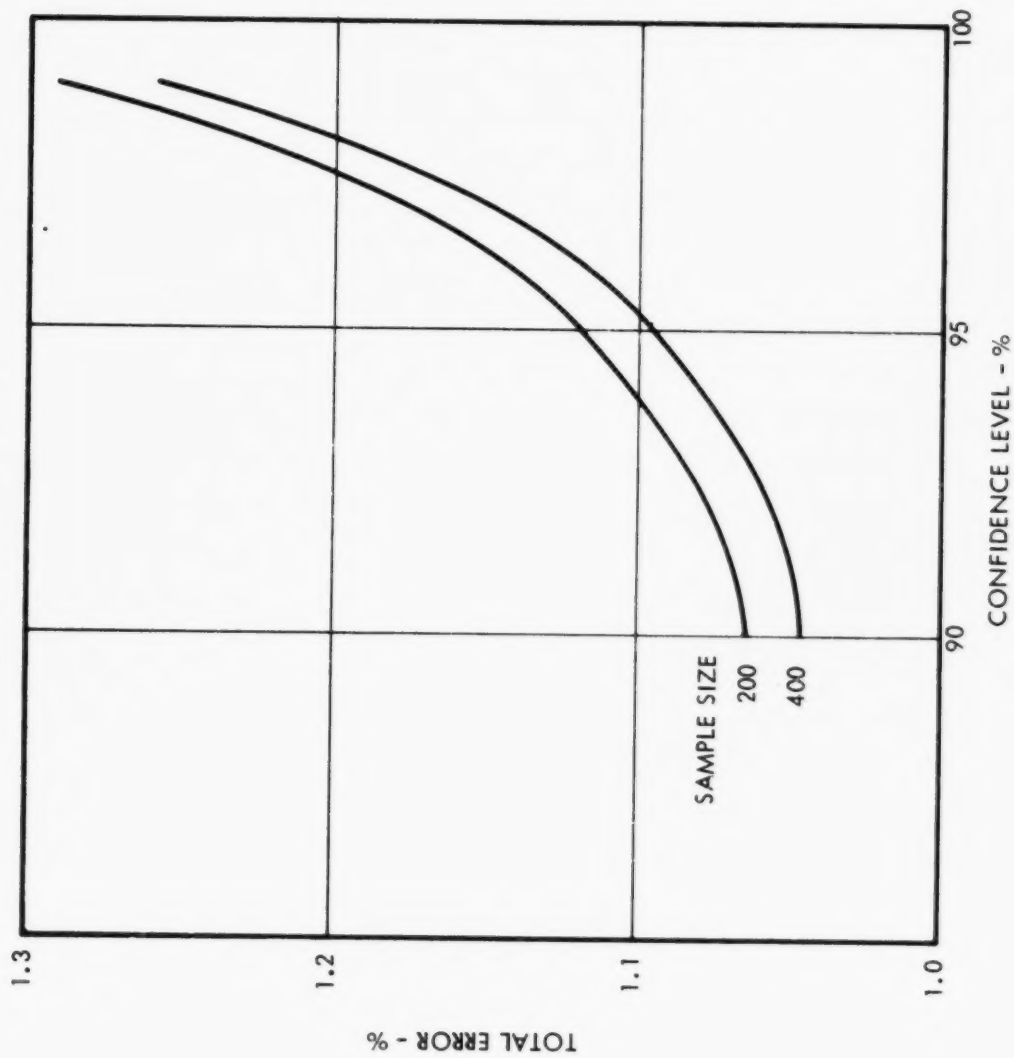
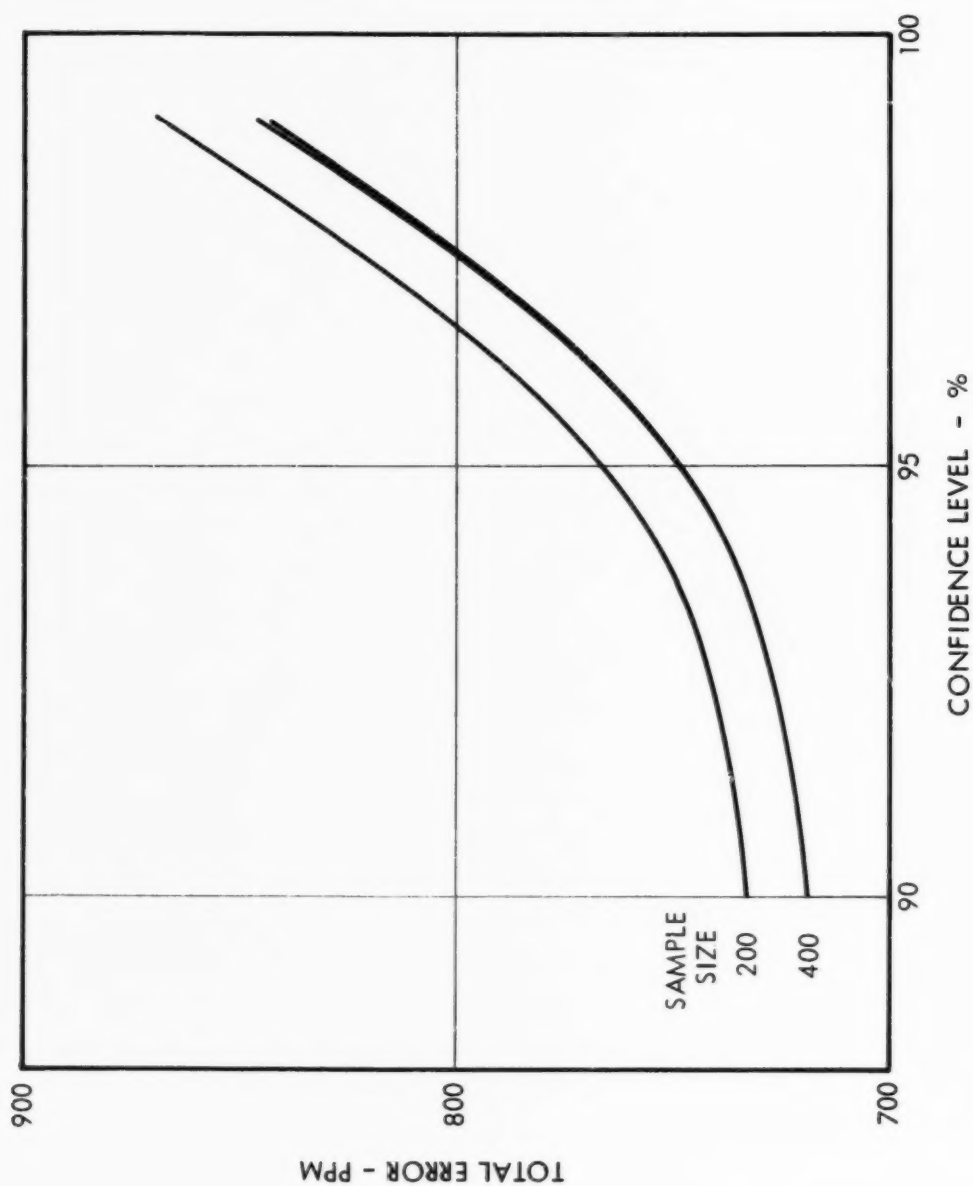


FIGURE 5-19

AFFECT OF CONFIDENCE LEVEL ON ESTIMATED TOTAL
NO STANDARD ERROR OF MEASUREMENT PROCEDURE

ACCELERATED COOL DOWN
NUMBER OF CYCLES = 3
BLOCK TEMPERATURE = 110°F



and test sample size at various confidence levels for two test procedural options.

Figure 5-20 indicates that HC exhaust emissions to the atmosphere can be determined with an error band of not more than 10% of the predicted mean value (18 ppm) with a confidence level of 95% if approximately 100 vehicles are tested using five replicated Federal cycles and hot-start temperature conditioning. If only three cycle replications were used, then approximately 225 vehicles should be tested for similar measurement results. If the error band for CO is to be less than 10% of its predicted mean (0.15%), then sample sizes of 150 and 260 vehicles would be required using test procedures which involve five and three replication of the 7-mode cycle, respectively.

Achieving greater statistical power requires increasing the required sample size appreciably. For example, the sample size must increase from 100 vehicles to 315 vehicles in order to state that the mean HC emission does not exceed 18 ppm at confidence levels of 95% and 99%, respectively. The cost impact of this change in test fleet size can, of course, be obtained by referring to Figure 5-5.

5.3.2 Confidence in Determining Regional Differences

The confidence with which regional differences in emission levels can be established is determined using estimates of the appropriate population standard error and sample size. The relationship between these statistics is given in Figure 5-22 for various values of α and β errors. If the chance of judging that a difference exists when in fact it does not (α error) and the chance of judging that a difference does not exist when it really does (β error) are both to be kept to less than 10%, for example, tests must be made on 200 cars in both of the regions in order to state that the populations differ when the measured difference, Δ/σ_T , equals 0.28. As an illustration, let us presume that CO emissions are to be compared between two regions using a stabilized hot-start test procedures involving either three or five replication of the 7-mode cycle. Figure 5-2 indicates that the expected standard error for the CO measurement using this procedure is 1.345 for three and 1.12 for five cycle replications, respectively. Using these

FIGURE 5-20
UNCERTAINTY IN PREDICTING MEAN HC EMISSIONS
TO THE ATMOSPHERE

ACCELERATED COOL DOWN
BLOCK TEMPERATURE = 100 °F

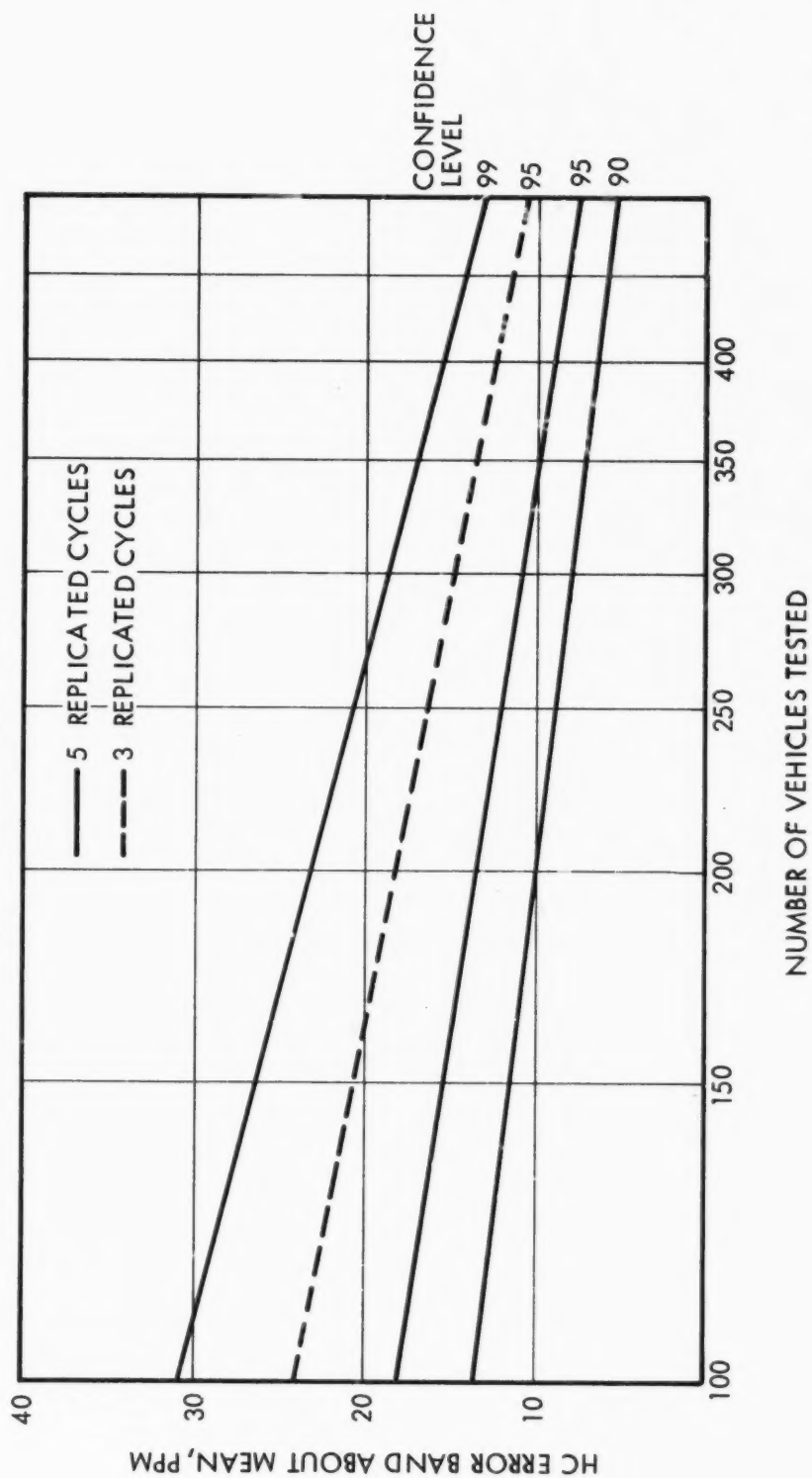


FIGURE 5-21
 UNCERTAINTY IN PREDICTING MEAN CO EMISSIONS
 TO THE ATMOSPHERE

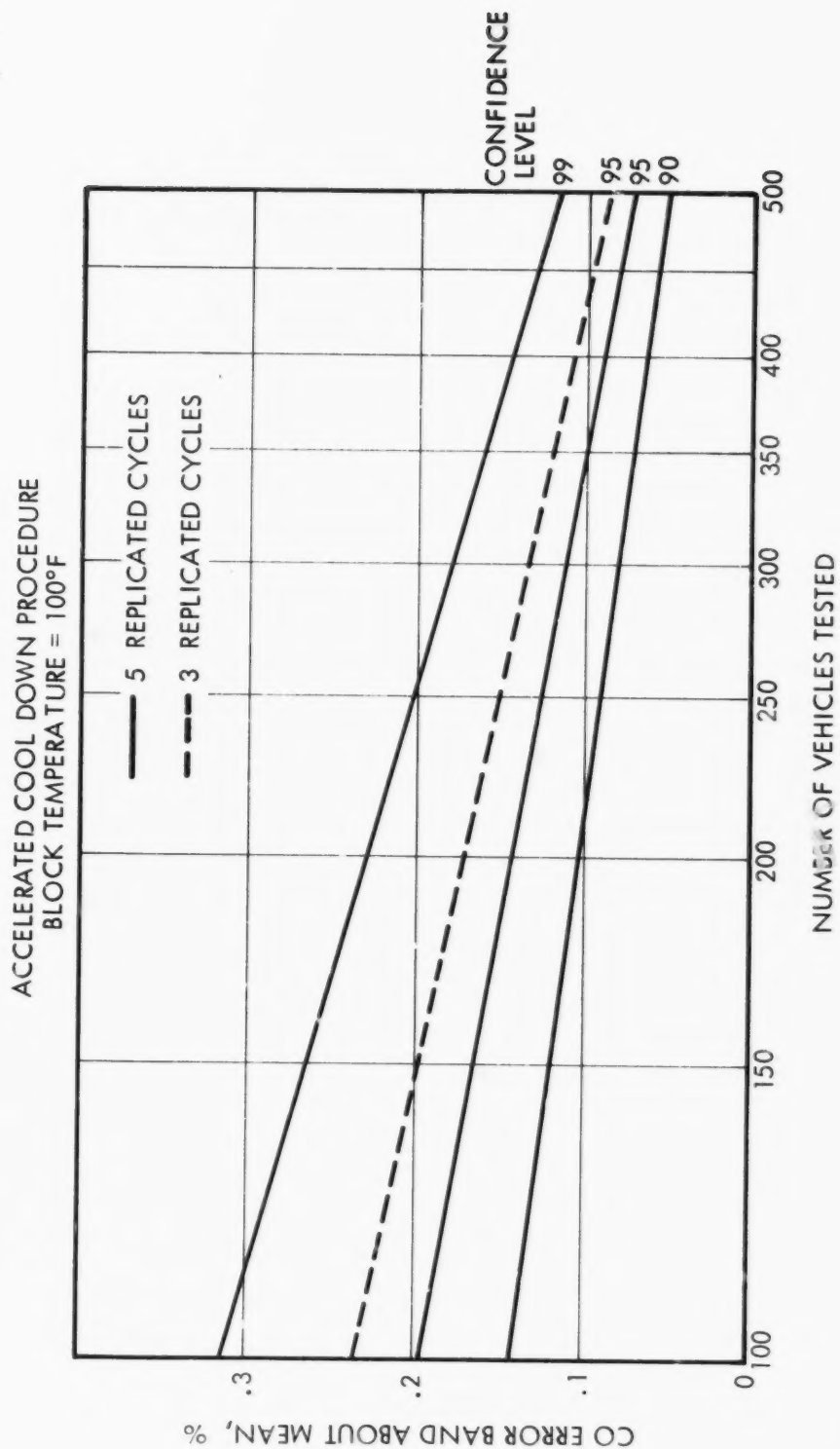
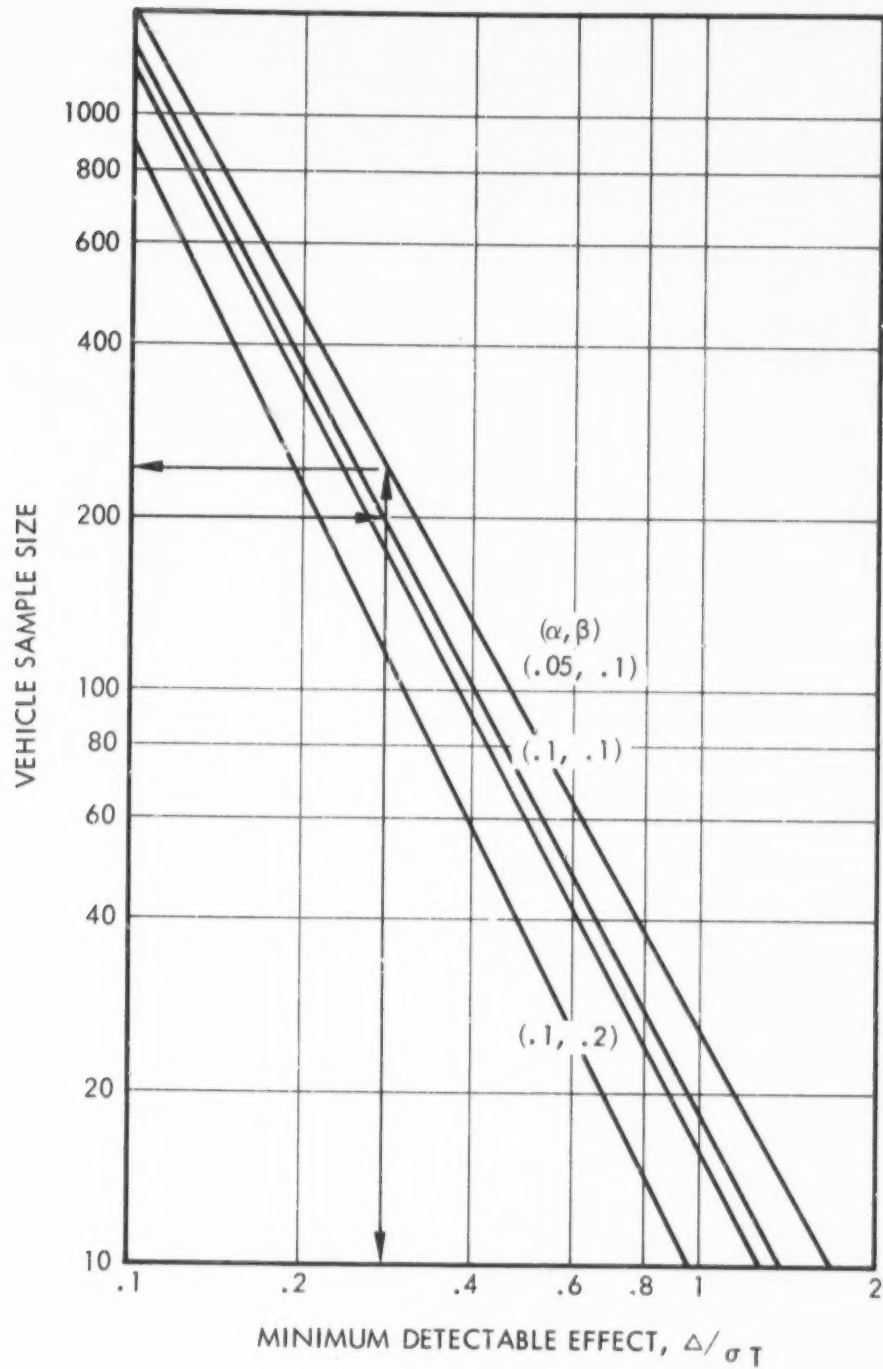


FIGURE 5-22

RELATIONSHIP OF DETECTABLE REGIONAL DIFFERENCES
TO FLEET SAMPLE SIZE FOR SEVERAL (α, β) RISK
COMBINATIONS



standard errors with the value of minimum detectable effect of 0.28, respectively, shows that the CO emissions must differ by 0.376% and 0.314%, for the two test procedural alternatives subject to limiting the α and β error risks to 10%. To make the same statement at a $\alpha = 0.05$, $\beta = 0.10$ would require 245 vehicles.

5.4 Recommended Surveillance Program Procedures

The results of the technical discussions presented in Sections 2.0, 3.0, 4.0, and 5.0 are applied in a recommendation for a surveillance program design. Two approaches are recommended, depending on the scope of the surveillance program. Those guidelines common to both approaches are presented first and consist of procedures for:

- Laboratory measurement control
- Vehicle identification and acquisition

5.4.1 General Guidelines

The general guidelines which were established for conducting a field surveillance program relate to (1) the methods for maintaining instrument standards to minimize precision (repeatability) and accuracy (bias) errors within and between laboratories and (2) procedures for identifying and acquiring a vehicle sample from a general population. The former procedure is important in characterizing the emissions of an individual vehicle whereas the latter procedure is important in predicting the overall population emissions level.

Laboratory Measurement Control

The following procedures are recommended for ensuring precise and accurate emissions measurements, both between and within laboratories. These procedures are intended to supplement and not replace those of the current Federal procedure, Reference 45 CFR Part 85.

- When more than one laboratory is performing a surveillance program, vehicles of the same general class should be divided equally between them to avoid regional or laboratory procedures biasing.

- Periodic cross-reference checks of instrument systems using known gases should be performed. Four to six different gas blends should be used, particularly, for CO and CO₂ which have highly nonlinear calibration curves.
- Calibration points (approximately six) should be fitted with a logarithmic curve (Beer's Law model); provisionally, it is suggested that the standard error of the curve fit should not exceed 1.0% of the full scale measurement nor should an individual calibration point differ by more than 3% from the value predicted by the curve fit.
- The general maintenance state of the instrument system should be monitored using quality control type charts of both the gain setting and mid-span point. Control limits should be selected which are compatible with the accuracy of the span gases used and the inherent instrument component performance.

Vehicle Acquisition

The following considerations should be implemented when selecting a vehicle sample from a regional population when a completely random sample is not withdrawn or for small samples (less than 250 vehicles):

- The sample vehicle attributes (mileage, cubic inch displacement, idle CO, and percent vehicles misfiring) should generally agree as to frequency and extent of those found in the general population.
- When surveying more than one model year, vehicles across model year may be pooled if they utilize generically similar control devices and have statistically similar emissions.
- When sampled vehicle populations have attributes which are statistically significantly different from the general population, the sample should be suitably adjusted or empirical corrections should be applied to the emissions data.

5.4.2 Optimal Procedures and System Configuration

Optimal procedures and system configurations were defined for three basic temperature conditioning test procedures:

- The current Federal procedure requiring a 12-hour vehicle conditioning at ambient temperatures
- Accelerated power train temperature conditioning to near ambient conditions
- Temperature conditioning to steady-state hot temperatures

For the latter two cases empirical correction factors were developed relating the emissions measured at a prescribed temperature state to those which would have been measured had the full Federal test procedure been used. The correction is essentially one to correct a bias error. However, this bias error correction can only be made with some uncertainty--it is this variability which is of interest and must be combined with other procedure errors to estimate a total procedure error.

Additional component errors estimated were those inherent to the measurement system, the within vehicle variability, and the between vehicle (population) variability. In the order listed above, the component emissions variability was found to increase progressively. For example, HC standard errors about the respective means were found to be 7 ppm, 27 ppm, and 97 ppm, respectively. Variables to be optimized include the general quality of the instrumentation, number of cycle replications, and vehicle sample size.

The above procedures were evaluated within the framework of stationary and mobile surveillance stations. The general conclusions reached are:

- The CO emissions variability, as reflected by the estimate of its population standard error, is larger than NO_x and HC emission and therefore will generally control the sizing of a test fleet.
- Relative to their mean emissions, both mass and concentration measurements have essentially identical within and between vehicle variability.
- Mass emissions (particularly CO) have significantly greater sensitivities to engine temperature state than do composite emissions.
- Regional biases may exist in emissions which are attributable to vehicle difference (i.e., maintenance state).

Specific conclusions reached with regard to test procedures and system configurations are:

- For vehicle sample sizes between 100 and 1000, the most error sensitive variable is the number of replicated driving cycles on an individual vehicle test; the most cost effective number of replications is five to six.
- The most cost-effective test procedure is five replicated test cycles starting from a hot temperature conditioned engine (100 vehicles or greater surveillance program).

- For relatively strong statistical statements concerning either vehicle emissions to the atmosphere or differences between regions, 250 to 300 vehicle samples per region are required.
- An accelerated cool-down procedure which recirculates cooling water through the block while blowing air over the radiator is cost-effective for surveillance samples greater than 240-500 vehicles, depending on whether HC and/or CO emissions are to be surveyed.
- Although the cost and figure of merit for the truncated procedures are substantially lower once the correlation of this procedure to the full Federal procedure has been established, the fixed cost of establishing the correlation tends to dilute this effectiveness for programs using small sample size.
- The requirement for higher confidence levels in estimating emissions to the atmosphere increases the cost of a surveillance program; for example an increase in confidence level from 95% to 99% requires nearly twice as many vehicle tests.

5.5 Recommended Follow-On Work

Based on the data presented in Sections 3.0 and 5.0 follow-on work is recommended in the following areas:

- Quantification of the procedure guidelines described in Section 3.0
- Evaluation of the impact of the pending Federal mass emissions test procedure on the general and specific conclusions of this report
- Evaluation of the impact of vehicle emissions compliance testing on the general and specific conclusions of this report.

Quantification of General Guidelines

The guidelines on intra- and inter-laboratory measurement standards as proposed herein require specific definition before they can be written into specifications. For example, data must be accumulated to establish reasonable control limits on instrument gain and calibration data. Specifically, historical data, where available, should be supplemented with contract developed data to establish control chart limits for the various emissions instruments. The procedures to be implemented as a consequence of an out-of-control process also requires definition.

A more precise procedure for statistically evaluating the results of reference cross checks is also required. Two approaches were applied in this study for comparing two or more laboratories. For the first case a regression of the measured level of the identical unknowns between laboratories was performed in order to obtain a confidence level on the slope and on the standard error of the regression. A statement that the regression slope coefficient is 1.00 at a high confidence level would indicate that no significant bias exists between facilities; a standard error for the regression within the capability of the instrument system would indicate good precision. This procedure could be extended to develop a confidence interval about the mean regression line.

Statistical techniques for evaluating multi-laboratory biases would also be of interest. A regression analysis of the interlaboratory standard error of the unknown reference against the estimated mean value of the unknown (Figures 2-10 and 2-11) could provide the basis for a control chart to determine anomolous instrument performance. For example, the standard deviation of the data point at 7.25% in Figure 2-11 indicates one or more laboratories may be out of control relative to the historical data.

Impact of Pending Mass Emissions Procedure

The impact of the pending change in test procedure from mode weighted volume measured emissions to mass weighted emissions was briefly discussed. Detailed, cost-effectiveness evaluations were not performed since data on vehicle population emission variances (i.e., equivalent EPA surveillance data) were not available. The analyses of nondimensionalized, within vehicle errors (Table 3-5) indicate a greater sensitivity of CO and NO mass emissions to the error components than the composite emissions. This, in turn, will affect the error resulting from correcting the emissions for bias effects caused by conditioning to temperatures greater than those of the Federal procedure. When mass emissions population data become available, it is recommended that procedure tradeoff studies be performed for a limited subset of the alternatives studied herein with the composite emissions data.

Impact of Compliance Testing

The current thrust for conducting surveillance programs is toward determining compliance of 25 engine families to the Federal standards. This requires the time-wise statistical comparison of the engine family mean emissions to the Federal standards. This comparison may be thought of as a one-sided acceptance test using control charts such as used for production or process control. The basic statistical decisions to be made are:

- The number of vehicles to be sampled within group and their time and/or mileage distribution over the period to be tested
- The frequency of either testing a captive fleet or randomly batch sampling from the entire population
- The attributes to be controlled in the sampling process
- The procedure for combining the engine family emissions measurements in order to estimate emissions to the atmosphere.

It is proposed that both costs and confidence levels for a null hypothesis (i.e., that the mean engine family emissions are equal to the standard) be developed as a function of total sample size. The user may then tradeoff statistical power for dollars to determine an optimal fleet size. Although primary emphasis is placed on the engine family sample size, tradeoffs in adjusting these samples for a more optimal estimate of emissions to the atmosphere should be performed.

The statistical procedures to be pursued in developing the above data are:

- Estimate engine family variance as a function of sample size
- Statistically evaluate the engine family emissions to assess their compliance with the Federal standards
- Develop an optimal procedure for combining engine family emissions to predict population means and variances.

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APPENDIX 1

REDUCED EMISSIONS DATA FROM
TEMPERATURE CONDITIONING EXPERIMENTS

TABLE 1
TEMPERATURE CONDITIONING DATA SUMMARY

Temperature and Mass Emission Data

Car No.	Run No.	Year	Make Model	CVS Mass Emissions			Temperatures	
				HC	CO	NO	Block	Carburetor
401	552	1968	Plymouth Baracuda	6.29	63.9	7.26	63	63
	3			4.00	20.5	8.83	129	113
	4			4.77	34.9	8.59	100	90
	5			4.75	44.3	7.51	96	85
	6			4.29	23.7	7.77	132	112
	7			3.79	18.2	8.14	132	120
	8			5.52	55.4	8.02	78	71
	9			4.77	35.4	7.91	112	92
	560			4.89	43.0	7.97	96	84
402	439	1968	Chevrolet Caprice				86	
	40			5.08	60.4	3.95	81	
	2			4.55	63.1	4.21	96	
	3			5.13	63.3	6.89	78	
	4			4.93	71.2	3.93	85	
	5			5.04	62.1	3.62	80	
	6			4.99	64.5	4.68	78	
	7			4.52	52.8	3.96	102	
	448			5.04	54.4	3.86	92	
								Not Taken
403	455	1966	Chevrolet Wagon	3.91	92.6	3.54	69	70
	6			5.08	70.4	-	88	82
	7			3.67	37.8	3.73	92	87
	8			3.90	68.1	4.11	115	102
	9			5.24	93.2	3.93	61	64
	460			4.83	91.8	3.74	87	81
	1			4.19	55.1	4.09	98	87
404	463	1967	Ford Sedan	6.91	310.0	1.39	71	71
	4			9.55	251.9	1.63	130	98
	5						84	76
	6			10.50	277.1	1.03	66	68
	7			8.51	268.4	2.31	83	75
	8			7.88	231.2	1.03	92	81
	9			9.45	251.3	1.43	71	70
	470			5.76	277.8	1.02	108	80
	1			9.15	254.7	.73	94	82
405	475	1969	Ford Mustang	5.14	23.5	9.26	72	74
	6			2.90	13.9	8.95	107	97
	7				17.3	10.22	90	89
	8			4.93	27.7	8.43	76	77
	9			4.06	16.2	8.79	96	89
	480			4.67	13.6	8.76	75	82
	81			3.78	14.3	7.55	88	80
	85			5.54	25.9	8.49	63	68
	86			4.26	17.0	10.38	102	84
	87			4.91	20.0	10.11	94	85

TABLE 1 (cont'd)

Car No.	Run No.	Year	Make Model	CVS Mass Emissions			Temperatures	
				HC	CO	NO	Block	Carburetor
406	490	1968	Ford Ranchero	5.54	19.2	6.47	123	98
	1			3.32	46.2	7.30	74	74
	2			6.15	25.8	6.28	123	96
	3			5.34	25.1	7.03	105	91
	4			5.33	27.5	7.23	100	88
	5			5.32	25.6	7.27	99	84
	6			5.22	32.9	7.06	73	78
	8			4.08	25.0	7.02	111	97
	9			5.22	29.5	7.1	99	93
407	502	1966	Dodge Polara	9.59	116.1	4.45	70	69
	3			3.90	82.9	5.47	105	101
	4			7.71	99.6	6.57	83	71
	5			7.46	99.9	5.43	95	89
	6			6.29	76.0	6.36	119	114
	7			10.27	129.2	4.42	67	66
	8			8.14	107.0	3.98	96	34
	9			8.56	111.6	4.19	85	79
408	512	1966	Ford Mustang	4.46	53.3	2.55	85	69
	3			5.38	63.4	2.20	66	69
	4			5.07	51.7	2.36	92	77
	5			7.20	63.7	1.95	81	75
	6			3.30	54.3	2.92	88	75
	7			4.73	49.7		88	74
	8			4.69	51.6	3.44	70	73
	9			3.28	34.8	3.26	79	94
	520			4.91	51.6	2.91	91	81
409	521	1968	Buick Electra				70	72
	2						90	87
	3			5.49	39.4	6.57	92	95
	4			5.66	45.4	5.96	101	94
	5			5.43	29.9	6.75	127	120
	6			5.83	49.2	6.62	72	72
	7			5.53	20.1	6.91	111	106
	8			5.84	37.0	6.68	94	90
	9			5.94	30.3	6.34	103	95
410	530	1968	Ford Fairlane	6.26	33.9	5.65	98	90
	535			4.80	36.7	3.78	88	75
	6			3.03	31.6	3.70	92	75
	7			4.65	22.0	4.69	132	90
	8						64	70
	9			4.48	22.4	5.72	117	90
	540			4.80	30.6	4.11	93	78
	1			4.80	32.1	4.09	83	76

TABLE 1 (cont'd)

Car No.	Run No.	Year	Make Model	CVS Mass Emissions			Temperature	
				HC	CO	NO	Block	Carburetor
411	570	1969	Plymouth Valiant				113	93
	1			2.99	37.9	9.16	70	70
	2			2.92	26.1	10.72	106	93
	3			2.80	36.7	9.75	90	83
	5						68	67
	6			3.23	63.3	9.37	92	84
	7			3.05	27.7	9.62	105	96
	8			3.60	30.5	7.75	94	84
	9			2.57	15.6	9.24	123	110
	580			3.58	35.5	9.58	64	69
	1						83	77

TABLE 2

TEMPERATURE CONDITIONING DATA SUMMARY

F=12 hr. cold soak; $\frac{1}{2}$, 1=hrs. of conditioning with water recirculation;
2,3=hrs. of conditioning with 30 mph fan air

Car Number	Run Number	Year	Make/Model	HC Composites			CO Composites		
				Cold	Hot	Composite	Cold	Hot	Composite
401 ↓	550	1968 ↓	Plymouth Barracuda	348	236	275	1.68	0.64	1.01
	552			470	283	348	2.83	0.78	1.50
	553			292	270	278	0.94	0.63	0.74
	554			372	250	292	1.68	0.62	1.00
	555			387	288	323	1.85	0.22	0.79
	556			309	275	287	1.07	0.64	0.79
	557			279	265	270	0.77	0.66	0.70
	558			501	301	371	0.95	0.69	0.78
	559			375	283	315	1.73	0.64	1.02
402 ↓	560	1968 ↓	Plymouth Barracuda	401	288	327	2.15	0.74	1.24
	439		Chevrolet Caprice	297	210	241	2.24	2.31	2.28
	440			276	184	216	2.31	1.94	2.07
	442			280	193	223	2.27	1.90	2.03
	443			329	189	238	2.52	1.96	2.16
	444			318	233	263	2.73	2.10	2.32
	445			269	236	247	2.62	2.01	2.22
	446			324	207	248	2.75	1.96	2.23
	447			254	218	230	2.39	1.83	2.03
	448			288	237	255	2.82	1.83	2.18
403 ↓	449	1966 ↓	Chevrolet Wagon	259	184	211	2.78	1.84	2.17
	453			428	239	305	4.46	1.98	2.85
	454			292	246	262	3.89	1.94	2.62
	455			369	218	271	4.05	1.73	2.54
	456			401	227	288	4.16	1.81	2.63
	457			315	217	251	3.86	1.64	2.42
	458			308	235	260	3.46	1.75	2.35
	459			336	224	263	4.25	1.48	2.45
	460			327	233	266	4.19	1.60	2.51
461 ↓	461	1966 ↓	Chevrolet Wagon	310	224	254	3.69	1.62	2.35

TABLE 2 (Cont'd)

Car Number	Run Number	Year	Make/Model	HC Composites			CO Composites		
				Cold	Hot	Composite	Cold	Hot	Composite
404 ↓	463	1967 ↓	Ford Sedan	539	431	469	8.52	6.85	7.43
	464			381	322	343	7.00	6.33	6.57
	465			488	341	392	8.72	7.20	7.73
	466			509	361	413	8.07	7.22	7.52
	467			460	344	384	8.07	6.63	7.13
	468			421	335	365	7.39	5.88	6.41
	469			493	326	384	8.00	6.17	6.81
	470			415	318	352	7.78	6.36	6.85
	471			426	325	361	7.54	5.97	6.52
405 ↓	475	1969 ↓	Ford Mustang	425	349	375	0.91	0.43	0.60
	476			374	306	330	0.45	0.47	0.46
	477			446	439	441	0.58	0.48	0.51
	478			438	313	357	1.38	0.48	0.79
	479			381	306	332	0.49	0.40	0.43
	480			396	318	345	0.99	0.50	0.67
	481			375	309	332	0.68	0.49	0.55
	485			537	303	385	1.50	0.49	0.84
	486			378	304	330	0.49	0.37	0.41
406 ↓	487	1968 ↓	Ford Ranchero	472	456	461	0.60	0.44	0.50
	490			437	345	377	0.56	0.68	0.64
	491			403	260	310	1.97	0.68	1.13
	492			354	283	308	0.84	0.67	0.73
	493			328	294	306	0.81	0.75	0.77
	494			354	331	339	0.90	0.69	0.76
	495			331	292	306	0.93	0.63	0.73
	496			312	284	294	1.05	0.66	0.79
	498			341	280	301	0.81	0.67	0.72
	499			319	298	305	0.94	0.65	0.75

TABLE 2 (Cont'd)

Car Number	Run Number	Year	Make/Model	HC Composites			CO Composites		
				Cold	Hot	Composite	Cold	Hot	Composite
407	502	1966	Dodge	473	248	327	3.76	1.41	2.23
	503		Polara	344	235	273	2.54	1.32	1.74
	504			405	223	287	2.86	1.31	1.85
	505			411	224	289	2.88	1.43	1.94
	506			332	227	264	2.04	1.39	1.61
	507			578	247	363	3.62	1.67	2.35
	508			458	263	331	3.31	1.46	2.11
	509			508	278	359	3.35	1.51	2.16
408	512	1966	Ford	546	427	469	3.37	1.93	2.43
	513		Mustang	625	478	529	2.06	1.83	1.91
	514			523	437	467	3.38	1.92	2.43
	515			519	465	484	3.69	1.81	2.47
	516			583	397	462	3.36	1.86	2.38
	517			524	427	461	3.38	1.49	2.15
	518			560	390	450	3.00	1.43	1.98
	519			486	381	418	3.00	1.42	1.97
	520			502	462	476	2.88	1.49	1.98
409	523	1968	Buick	249	256	254	1.23	1.17	1.19
	524		Electra	283	250	262	1.66	1.13	1.32
	525			277	274	275	0.96	0.90	0.92
	526			300	255	271	2.03	0.47	1.01
	527			251	278	268	0.88	0.37	0.55
	528			291	284	287	1.58	0.36	0.78
	529			284	271	276	1.10	0.40	0.65
	530			332	288	304	1.31	0.41	0.73
	531			323	265	285	1.90	0.44	0.93
	532			294	286	289	1.28	0.36	0.68

TABLE 2 (Cont'd)

F = 12 hr. cold soak; 1/2, 1 = hrs. conditioning with water recirculation; 2, 3 = hrs. of conditioning with 30 mph forced fan air

Car Number	Run Number	Year	Make/Model	HC Composites			CO Composites		
				Cold	Hot	Composite	Cold	Hot	Composite
410 ↓	535	1968 ↓	Ford	282	300	294	0.72	0.62	0.66
	536		Fairlane	305	286	293	1.08	0.57	0.75
	537			278	309	298	0.69	0.66	0.67
	538			342	281	302	1.65	0.52	0.92
	539			270	273	272	0.75	0.58	0.64
	540			273	308	296	1.10	0.63	0.79
	541			266	309	294	1.25	0.57	0.81
	542			313	236	263	1.52	0.56	0.90
	543			292	257	269	1.20	0.57	0.79
411 ↓	570	1969 ↓	Plymouth	263	202	223	1.55	0.88	1.12
	571		Valiant	319	207	246	2.16	0.95	1.37
	572			272	225	241	1.57	0.43	0.83
	573			282	198	227	1.94	0.98	1.31
	574			309	197	236	2.26	0.44	1.08
	575			311	189	232	2.12	1.00	1.39
	576			287	197	228	1.75	0.85	1.16
	577			269	208	229	1.72	0.95	1.22
	578			239	181	201	1.75	0.89	1.19
	579			226	169	189	1.27	0.91	1.04
	580			294	170	214	2.13	1.09	1.45
512 " "	508	1970 "	VW1500	442			5.32		
	509			471			5.30		
	510		"	507			5.81		